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THE FORMATION OF COAL BEDS.

I.

AN HISTORICAL SUMMARY OF OPINION FROM 1700 TO THE PRESENT
TIME.

By JOHN J. STEVENSON.

(*Read April 21, 1911.*)

PRELIMINARY NOTE.

Preparation of a monograph on any subject which interests students in many lands requires thorough study of the literature as a preparatory step. But that literature has grown to such proportions that one often becomes discouraged and is burdened with the fear that life will be spent in making ready and that the grave will have been reached before the monograph has been begun. Yet such preliminary research is not without compensation, for one discovers that his own period is not so far in advance of days gone by as he had supposed; that his contemporaries, with all their advantages, have done little more, in many instances, than to place newer and finer clothing on the generalizations of earlier students who had worked within narrower areas.

This is not to say that modern workers have appropriated knowingly the results obtained by their predecessors. The writer has discovered very few instances of that sort. For the most part, generalizations have been made, *de novo*, in ignorance of those previously formulated. The literature has become vast; the papers are scat-

tered in publications of many societies in six or more languages; many were merely separate pamphlets, now almost inaccessible. Great scientific libraries are few and they are beyond reach of the ordinary field-worker; while college professors and men connected with official surveys rarely have leisure needed for thorough research. The necessity for prompt publication, that fellow workers may have the advantage of one's results, makes long preliminary study almost impossible, in some cases almost unjustifiable.

The writer, looking forward to preparation of a monograph on formation of coal beds, has examined many hundreds of publications varying from mere notices to ponderous quartos and this preliminary work is still far from complete. During the examination, he has discovered not only that there is little new under the sun but also that much, which is good and important, soon passes from men's minds. He has discovered also that owing to quotation at second-hand, without verification, some conclusions offered by the earlier students have been misunderstood or even misinterpreted, so as to discredit the authors. He has become convinced that a systematic presentation of conclusions reached by his predecessors would not be useless or unacceptable; it would exhibit the gradual development of opinion and it would lead to proper appreciation of investigations made and conditions, which, in this day, would be regarded as unfavorable; it would aid the students hereafter by indicating the road along which to pursue his preliminary examination. Such presentation is offered in the succeeding pages.

In preparing this historical summary, the writer, recognizing the necessary limits of space, is compelled to note only such publications as deal especially with the topic under consideration; and of those, only such as are the outcome of direct study. The reader may be disappointed by the omission of some authors and by the admission of others; but this is unavoidable. Many important reflections have been made by writers incidentally; those will be noted in the final discussion. No reference to opinions respecting the origin of coal is given, except in cases where that question is basis of the author's conclusion respecting the mode of accumulation.

The plan of the summary may be open to criticism. The

original plan was to arrange the synopses topically, but this separated the contrasting opinions of contemporaries; the chronological arrangement is open to the objection, that it breaks up the line of argument for or against an hypothesis. Yet the latter seems preferable as more in accord with the purpose of the summary. It has been followed, except where it would fail to show an author's final conclusions or where it seemed necessary to bring together widely separated observations upon a special phase.

THE HYPOTHESES.

There has been little diversity of opinion respecting the origin of coal. Geologists and chemists, with rare exceptions, have recognized that the several types consist mainly of vegetable matter which has undergone chemical change. But no such consensus of opinion exists respecting the mode of accumulation in beds; geologists, for about one hundred and thirty years, have been divided into two opposing camps with here and there an individual warrior carrying on an independent strife.

The older hypothesis was suggested more than two centuries ago, prior to the era of investigation, and it remained unchallenged until the latter part of the eighteenth century, but it fell into disfavor early in the nineteenth century. Thereafter, it had few, but earnest defenders until within the last thirty years, during which it has been urged with great energy. This, the doctrine of allochthonous origin, conceives that coal beds are composed of transported vegetable matter deposited in the sea or in lake basins. The conception has assumed many forms but the essential feature of transport is common to all.

The other hypothesis, formulated in 1778 as the result of broad field observations gained general acceptance about one hundred years ago; since that time, it has been held in one form or another by a majority of geologists who have studied the coal measures. It is known as the doctrine of growth *in situ*, but von Gümbel's term, autochthonous, has come into general use. According to this hypothesis, the plants which yielded the vegetable matter grew where the coal is found, analogous conditions being found in great peat accumulations, especially those of the cypress swamps of North

America. That additional material may be brought in from time to time by transport is conceded, but the quantity thus added is comparatively unimportant. Equally the formation of a coal deposit by transport is conceded but not the formation of a typical coal bed.

THE SYNOPSES OF OPINIONS AND RESULTS.

Woodward¹ explained all stratified rocks as deposits from the original menstruum. During the time of the deluge, the solid materials were wholly "dissolved." They were mingled with unconsolidated materials such as sand, earth as well as animal and vegetable matters and all were assumed and sustained by the water in a confused mass. In time, these materials subsided "as near as possibly could be expected in so great confusion, according to the laws of gravity," those having the least gravity settling last of all and covering the rest. "The matter, subsiding thus, formed the strata of stone, of marble, of coal, of earth and the rest." That Woodward thought coal to be of vegetable origin cannot be determined with certainty; his remark that vegetable materials, being of less specific gravity than mineral matter, would be precipitated last of all and so form the outermost "stratum of the globe" seems to suggest a contrary belief.

Whiston² took issue with Woodward and asserted that the hypothesis presented by that author "includes things so strange, wonderful and surprizing that nothing but the utmost Necessity, and the perfect unaccountableness of the Phenomena without it, ought to be esteemed sufficient to justify the Belief and Introduction of it." At the time of the Noachic deluge the earth passed through the "Chaotick Atmosphere of a Comet" and thus acquired a great amount of new material which mingled with the loose materials of the globe. These subsided according to the laws of specific gravity, giving the strata of stone, earth and coal; in all about 105 feet thick. Whether the coal is terrestrial or cometary in origin cannot be ascertained by study of this work. The author's conclusions are

¹ J. Woodward, "An Essay Toward a Natural History of the Earth and Terrestrial Bodies," 2d ed., London, 1702, pp. 73, 74, 77.

² W. Whiston, "A New Theory of the Earth," 4th ed., London, 1725, pp. 277, 278, 365, 419, 423, 425.

fortified by a wealth of mathematical proof which, apparently, leaves little to be desired.

Scheuchzer³ described a deposit of black slate in the canton of Glarus, occurring in layers, one third of an inch thick, each consisting of a hard upper and a soft lower lamina. The phenomena observed in the quarry led him to assert "This is now certain that all rock beds were formed by precipitation, through subsidence of heavier earthy particles in a fluid menstruum, especially the waters of the Deluge. The observed difference of materials in every layer as well as the orderly parallelism of the layers is a sufficient proof of this. . . . At times all sorts of relics of the Deluge, fish and vegetables occur in these shales." Scheuchzer saw in the coal merely the remains of wood swept off during the deluge, "Wherefore here and there stone coals are found which were true wood"; and he notes the existence of deposits at 18 to 24 yards below the surface. This is his "*Lignum fossile ex Sylva submersa*."

De Jussieu,⁴ about 1740, observed, near St. Chaumont in France, many impressions of plants very different from those now existing. He remarked that these represent true plants and that they lie flat as in a herbarium. In seeking their origin he was led to believe that they were vegetation of a warm climate and that they had been transported. The sea covered the continents; the currents carried and deposited the plants and shells which are found petrified.

Few writers prior to the middle of the eighteenth century dealt in other than *a priori* arguments but, after half the century had passed, there came numerous observers whose labors were utilized by Buffon.

Buffon⁵ recognized the vegetable origin of coal and asserted that its excellent quality is due to the intimate mingling of vegetable matter with bitumen—the latter being only vegetable oil or animal fat impregnated with acid. He designates coal as "*Charbon de*

³ J. J. Scheuchzer, "*Meteorologia et oryctologia helvetica*," Zurich, 1718, pp. 110, 111, 239, 240.

⁴ A. de Jussieu, cited from Saporta by L. Lesquereux, 2d Geol. Survey of Penn., Ann. Rep. for 1885, p. 95.

⁵ L. de Buffon, "*Histoire naturelle, generale et particuliere*," Sonnini Ed., T. 9me., Paris, An IX., pp. 11, 14, 16, 35, 36, 42-46. The original publication was in 1778.

terre" and restricts the term "houille" to "the black combustible earthly deposits which are often found over and sometimes under the coal beds." These are simply mold mixed with a small amount of bitumen. The slime deposited in the sea, following the slope of the bottom and extending at times for several leagues along the coast is nothing other than the mold of plants and trees, which is drawn off by running water. The vegetable oil of that slime, seized by acids in the sea, will become in time bituminous coal but always light and friable; while the plants themselves, drawn off in like manner and deposited by the waters form the true beds of charbon de terre, of which the characteristics are very different from those of houille, the charbon being heavier, more compact and swelling in the fire.

The dips of the coal are due to the general law of deposit in moving water, while at the same time the materials have taken the inclination of the surface on which they were laid down. Occasionally the dip approaches the vertical, but even that great inclination gradually approaches the horizontal more and more as one descends and at last the horizontal plane, the plateau, is reached. A usual feature is that the thickness of a coal bed increases with the depth and the maximum is *en plateau*—which is in accordance with the law of deposit of materials carried by water and laid down on a sloping surface. The same law applies to other materials, whereby is explained easily the parallelism of coal beds to each other and to the intervening strata.

Von Beroldingen⁶ published his work in the same year; it was based on broad field study. In it the author maintained that stone coals had originated from brown coals and those in turn from peat. This appears to be the first definite assertion of the peat-bog or *in situ* hypothesis.

De Luc⁷ published the same theory during the next year in the

⁶v. Beroldingen, "Beobachtungen, Zweifel und Fragen, die Mineralogie betreffend," Erster Versuch, Hannover, 1778. The writer has been unable to find a copy of this work. It is cited by De Luc (1779), Mietzsch (1875) and by several other authors.

⁷J. A. De Luc, "Lettres physiques et morales sur l'histoire de la terre et de l'homme," Paris, 1779, Tome V., pp. 213-25. This 126th letter is dated Oldenburg, September 16, 1778.

last of five letters describing the peat deposits of northern Europe. During his journey across Germany and the Baltic he had made many exact observations on bogs; he had followed the great level marshes of the shores up the Weser river to the inland moors and had found the same general features throughout. He describes the slipping of the swamp into the river where, by swelling, it formed a hard dry rampart which prevented all further ingress of water to the swamp. He notes the great flood of Jutland, due to subsidence of the boggy area, which is covered at low tide. On the island of Bornholm in the Baltic is a swamp, surrounded by dunes, which shows many prostrate firs, pointing toward the center of the bog. These trees were overthrown by wind when the peat was soft. He observed that dry peat produces very fine trees, those growing on the peat ramparts of Oldenburg being beautiful. His observations led him to assert that

“The peat is the origin of the pit-coals or charbons de terre.” He states in a footnote that he had been anticipated by v. Beroldingen, but that he had arrived at this conclusion independently while studying the immense peat bogs of Bremen. He recalls that islands had sunk below the ocean surface; some of them might contain peat as Bornholm. The waters would deposit matter on the peat giving the shaly roof mingled with leaves of vegetables which covered the peat at time of submergence. New sea deposits accumulated and the peat, compressed, enclosed as in a laboratory, underwent further change. He acknowledges that there may be difficulties in explaining the transmutation of peat and the arrangement of some coal beds, but he is confident that he is on the true road to the proper explanation of the origin of coal and of its occurrence in beds.

An anonymous writer,⁸ in 1781, sums up the peatbog theory as presented at that time.

It is a received opinion amongst many naturalists, that coal was originally peat moss, this fossil having been found in every intermediate state, nay, sometimes with wood in it, and often with the marks of leaves, roots, branches, and fruits of different plants, shrubs and trees, on the sides of broken fragments. To this doctrine we were made proselytes, being pre-

⁸ “A Tour to the Caves in the Environs of Ingleborough and Settle in the West-Riding of Yorkshire,” London, 1781, p. 68.

sented with some pieces of coal that were got near the top of Whernside and the other mountains, that seemed more like dry clods of peat moss than coal, though distinguishable enough to belong to the latter class. The principal difference in their composition is that coals abound with the vitriolic, and peat moss with the vegetable acid. The vitriolic acid is diffused through every subterranean stratum; hence if a quantity of earth should be superinduced above a stratum of peatmoss, the vitriolic acid that would ouse through, must in time change its nature and turn it into coal: the deeper it lay below the surface of the ground, the more it would be impregnated with this fossil acid, and consequently be the more inflammable. If a stratum should lie near the top of a mountain, there is the less chance that it should be well fed.

Williams⁹ was an uneducated man but an admirable observer, who summarized in his volumes the results of studies in much of Great Britain. He was a firm believer in the vegetable origin of coal and equally in the wide extent of the Noachic deluge. Thinking that he could identify in some coals the wood of modern species, he suggested that, prior to the deluge, only a small part of the globe was inhabited and that most of it was covered with tall trees. Those trees, swept off by the deluge, were carried by currents and deposited in limited areas. But this hypothesis does not satisfy all the conditions, for he had found coals which closely resembled peat. He says, "I will here beg leave to propose another probable source of coal. I believe I may call it a real one, and that is the antediluvian peat bog," and this is followed by a discussion of peat bogs, their structure and growth.

Williams argues strenuously against any hypothesis that the materials of the strata were formed by settling of particles from a heterogeneous mass in accordance with gravity, for the order of the beds is evidence to the contrary. At the same time, he finds in the structure of coal beds evidence that most of the beds were formed of transported timber. "I am of opinion that the antediluvian timber floated upon the chaos or waters of the deluge, . . . and that during the height of the deluge and the time in which the greatest part of the strata were forming, the timber was preparing and fitted for being deposited in strata of coal."

⁹ J. Williams, "The Natural History of the Mineral Kingdom," Edinburgh, 2d ed., 1810, Vol. 1, pp. 510, 522-525. The first edition was in 1789.

Darwin¹⁰ adhered to the doctrine of formation *in situ* but with modifications. "In other circumstances, probably where less moisture has prevailed, morasses seem to have undergone a fermentation, as other vegetable matter; new hay is liable to do so from the great quantity of sugar it contains. From the great heat thus produced in the lower part of the morass, the phlogistic part, or oil or asphaltum, becomes distilled and, rising into higher strata, condensed, forming coal beds of greater or less purity, according to their greater or less quantity of inflammable matter; at the same time the clay beds become poorer or less so as the phlogistic part is more or less completely exhaled from them."

Patrin,¹¹ cited by Parkinson, thought coal and the interposed beds of rock due to alternating ejection of bituminous and earthy materials by submarine volcanoes. In another work cited by Pinkerton he describes the characteristics of coal beds, that they have a boat-like form and that they are never single, there being many in each coal field. He thinks the deposit must have been made in still water. The occurrence of plant impressions in the roof shales has led several naturalists to think that coal is composed of vegetable remains. But Patrin thinks that this opinion presents great difficulties. The naturalist le Blond found beds of coal near Bogota at 13,200 feet above the sea. When the ocean reached that height there would be islands; and it cannot be seen how the small quantity of vegetables, which had been brought accidentally from those mountains, could have formed the thinnest bed of coal or even of peat.

Hutton's¹² opinions appeared in final form in 1795. They are not always stated clearly but the confusion may not be that of the author's mind; it may be only apparent and due to the somewhat involved method of presenting the case. The carbon of coal is evidently of organic origin. Bituminous coal and anthracite are parts

¹⁰ E. Darwin, "Botanical Garden," Add. Notes, XVII., 1791. Cited by J. Parkinson; not seen by the writer.

¹¹ Patrin, Art. Houille, "Dict. d'hist. Naturelle," cited by Parkinson; "Minéralogie, V., p. 317. Cited by J. Pinkerton in "Petrology," pp. 567, 568.

¹² J. Hutton, "Theory of the Earth With Proofs and Illustrations," Edinburg, 1795, Vol. I., pp. 565, 566, 570, 575-581, 586.

of a series, the latter having been derived from the former by the influence of heat, which itself was the agent by which vegetable matter was converted into coal. Fuliginous matter is given off when vegetable materials are burned and it is just what is needed to compose coal beds. There are many charred coal beds, which have lost their volatile or fuliginous matter through subterranean heat. The volatile matter, diffused through the water, aided in formation of the strata, while smoke from burning bodies on the land found its way to the sea where it settled to the bottom. But this was not the only source. The rivers of Scotland carry brown water from the bogs; there must be some agency causing precipitation of this brown material, otherwise the sea would be impregnated with oily substance. The constant perishing of plants and animals would give a supply of oily or bituminous matter to the ocean, which would become pure coal unless earthy stuffs be in the water, which would render the coal impure. If the mixture be perfect and the subsidence uniform, a homogeneous substance resembling cannel would be formed.

Therefore, with regard to the composition of mineral coal, the theory is this, that inflammable vegetable and mineral remains, in a subtilized state, had subsided in the sea, being mixed more or less with argillaceous, calcareous and earthy substances in an impalpable state. Now the chymical analysis of fossil coal justifies this theory; for in the distillation of the inflammable or oily coal, we procure volatile alkali, as might naturally be expected.

Kirwan,¹³ indignant at Hutton's generally iconoclastic views, entered the lists evidently determined to annihilate the new doctrines as well as their author. He rejects the hypothesis that pit coal is merely earth or stone impregnated with petrol or asphalt, for Kilkenney coal contains neither petrol nor any other bitumen. He recognizes the vegetable origin of wood coal but maintains that it is chemically different from mineral coal, so different as to show that the latter was not derived from wood deposited in or out of the sea. As further arguments, he notes features in the mode of occurrence. Beds of mineral coal are uniform in thickness within great areas, beds of wood coal are not; beds of mineral coal show parallelism, which is unknown in wood coal beds; wood coal mines

¹³ R. Kirwan, "Geological Essays," London, 1799, pp. 315-349.

have sudden elevations or depressions, not found in those of mineral coal; slips or dikes abound in true coal but do not occur in wood coal; wood coal is frequently, genuine coal never found in plains. Mineral coal is of distinctly inorganic origin.

My opinion, therefore, is that coal mines or strata of coal, as well as the mountains or hills in which they are found, owe their origin to the disintegration and decomposition of primeval mountains, either now totally destroyed, or whose height and bulk, in consequence of such disintegration, are now considerably lessened. And that these rocks, anciently destroyed, contained most probably a far larger proportion of carbon and petrol than those of the same denomination now contain, since their disintegration took place at so early a period.

The seams of coal and their attendant strata must have resulted from the equable diffusion of the disintegrated particles of the primitive mountains carried down by the "gentle trickling of the numerous rills" and more widely diffused by more copious streams. The important sources of material for the coal beds were granite and trap, as those rocks contain natural carbon and hornblende, the latter mineral being an extremely important source. Kirwan's arguments are extremely ingenious and he finds no difficulty in explaining all known phenomena by means of his "supposition."

Playfair¹⁴ attacked Kirwan's doctrine and defended that of Hutton. He regarded Kirwan's suggestions as deserving only ridicule. He showed that both wood and mineral coal occur in the same bed and that most of Kirwan's postulates were not in accord with fact. The quantity of hornblende and silicious schist to be decomposed in order to yield the coal would be vastly greater than Kirwan had supposed; Playfair suggested that it would have been better to imagine that the diamond existed so abundantly in the primeval mountains as to constitute great rocks. A single ridge might suffice to give material for coal beds of all the surrounding plains. He asserted that Kirwan's hypothesis trespasses on every principle of common sense.

Voigt¹⁵ strenuously opposed v. Beroldingen's hypothesis that coal

¹⁴ J. Playfair, "Illustrations of the Huttonian Theory of the Earth," Edinburgh, 1802, pp. 148-160.

¹⁵ J. C. W. Voigt, "Versuch einer Geschichte der Steinkohlen, der Braunkohlen und des Torfes," Weimar, 1802, pp. 42-46.

beds originated as peat bogs. He believed that coal was formed chiefly from the harder species of reeds, and the vegetable matter had been dissolved in an oily substance. The fluidity of the material is proved by the occurrence of thin streaks in sandstone as well as by carbonaceous shale, which contains enough combustible matter to be utilized as fuel. The opinion that stone coal was at one time brown coal and that, in turn, originally peat deserves no consideration; it is merely the notion of a closet student and Voigt is surprised that Beroldingen, who had seen so many localities of stone and brown coal and peat, should offer the suggestion. Stone coal belongs to the oldest formations while brown coal and peat are of the newest; one might as well suggest that a child begat its mother, and the mother, the grandmother. It is sufficiently clear that Voigt conceived that the vegetable matter was first converted into bitumen and then transferred. His memoir was crowned by the Gottingen academy. The prominence thus given to it as well as the emphatic manner in which its assertions were made did much to repress the readiness shown by contemporaries to accept the Beroldingen hypothesis in whole or in part.

Faujas-St.-Fond¹⁶ discussing the source of coals occurring in what he terms granitic regions, says that they were deposited in bays or vast basins excavated by the sea. Currents transported into these receptacles materials from the granites, which became beds of greater or less thickness. Sometimes the seas brought the plants which, along with animals so abound in them, and these accumulated *pêle mêle* with the products of terrestrial vegetation brought down by the rivers. At other times the tides deposited on these beds of combustible materials the quartz sand of the sea bottom; at later periods, wood and plants arrived again, were deposited on the sands or clays; thus were formed the alternating beds of vegetable material with combustible residues of fish, mollusks and marine plants.

Al. Brongniart¹⁷ described in detail the various types of coal, lignite and peat. He evidently accepts Voigt's conclusion that there is no bond between coal and lignite, while at the same time he hesi-

¹⁶ B. Faujas-St.-Fond, "Essai de géologie," Paris, 1803, p. 443.

¹⁷ Alex. Brongniart, "Traité élémentaire de minéralogie avec des applications aux arts," Paris, 1807, t. 2, pp. 13, 14, 32, 36.

tates to accept the doctrine that coal is product of decomposition of organized bodies. Brongniart exhibits much caution in respect to generalizations but offers these conclusions which he thinks are derivable from actual observation: (1) That the coal is a formation contemporaneous with or posterior to the existence of the organized bodies; (2) that this combustible, when it was deposited or formed, was liquid, homogeneous and in a great degree of fineness, which is proved by the frequently parallelopipedonous structure and by the manner in which it is absorbed by the beds which enclose it; (3) that the cause, which has deposited or formed it, was renewed several times in the same place, with conditions almost the same; (4) that this cause has been the same for almost all the earth, since the coal beds present in their structure and their accessory conditions almost always the same phenomena; (5) that these beds have been deposited without violent disturbances, since the organized bodies which are found in them are often entire and since the leaves, which are impressed on the shales covering the coal, are expanded and are hardly ever rubbed or even folded.

Parkinson¹⁸ regarded coal as a product of vegetable matter reduced to fluidity by bituminous fermentation; this fluid suffered modification of its inflammability by deposition of carbon and by intimate admixture with various salts. The vegetable matter had been swept into the sea by the universal deluge.

Kidd¹⁹ summarizes the doctrine of transport thus, "Powerful floods have swept away forests and subsequently covered them with the ruins of the soil in which they grew; whence those beds of clay and gritstone which so generally accompany the coal itself." His objections to this doctrine are that remains of trees and shrubs are wanting; that the plants are evidently those of many places; that the mechanical force, which uprooted the forests and swept away the vegetable matter as well as the greater amount of the earthy matter in the shales and gritstones, must have been extreme; yet the particles of the grit are not rounded and show no sign of attri-

¹⁸ J. Parkinson, "Organic Remains of a Former World," London, 1811, Vol. I., p. 248.

¹⁹ J. Kidd, "A Geological Essay on the Imperfect Evidences in Support of a Theory of the Earth," Oxford, 1815, pp. 126, 127, 128.

tion. He objects further that the theory does not account for the alternation of calcareous with argillaceous and siliceous beds, and asks on what principle one may expect that beds of earth spread out by the floods, should be periodically calcareous, argillaceous or siliceous, and how can it account for the alternations of clay beds with numerous coal beds; why should a second flood in its blind fury deposit a second series of beds on exactly the same spot where the first series is deposited?

Conybeare²⁰ adhered to the belief that vegetable matter alone was the source of coal and accepted Sternberg's suggestion that torrents tore off the vegetation from scattered primitive islands to deposit at the bottom of adjacent basins. He conceived at this early date a theory having not a few of the features characterizing one offered at a much later date. He thinks that the coal measures were deposited in estuaries and that the partial filling up of lakes and estuaries offers us the only analogies in the actual order of things with which the coal deposits can be compared. Respecting the deposit at Bovey Tracy, he says:

We must here suppose the wintry torrents to have swept away a great part of the vegetation of the neighboring hills and buried them in the estuary with the alluvial detritus collected in its course; the latter would, from its gravity, have sunk first and formed the floor; the wood would have floated till, having lost its more volatile parts by decomposition and become saturated with water moisture, it likewise subsided upon them, being perhaps loaded by fresh alluvium drifted down upon its surface; the re-iterated devastations of successive seasons must have produced the repetition and alternation of the beds . . . and if we suppose a like order of things to have operated more extensively and for a longer period during the formation of the coal strata, we shall find such an hypothesis sufficiently in accordance with their general phenomena.

Ad. Brongniart,²¹ after long study of the fossil plants, concluded that in the Carboniferous time the dry land was confined to islands on which grew the plants whose remains are in the coal formation. Numerous proofs established that the plants grew in the very places where they are found or, at most, within only a little distance away.

²⁰ W. D. Conybeare, "Outlines of Geology of England and Wales," London, 1822, pp. 334, 345, 347.

²¹ Adolphe Brongniart, "Prodrome d'une histoire des végétaux fossiles," Paris, 1828, pp. 183, 184.

The manner in which the plants are preserved in rocks accompanying coal beds as well as the presence of vertical stems in normal position are most convincing. He cannot attribute the formation of coal beds to accumulation of vegetable detritus transported from a distance and deposited in the condition of pulp (*bouillée*) as was supposed by Sternberg and Boue. In fact it would be difficult to understand how the causes, which reduced to a kind of pulp the plants which have formed the coal itself, failed to change the plants found in the neighboring beds; how it is that the coal formed in the sea contains no marine debris; how, finally, a substance thus deposited shows no more inequalities in thickness of the bed. He accepts De Luc's conception of vast swamps as best agreeing with observed conditions. The intervening rocks originated during periods of elevation of the sea-level or depression of the land.

Ure²² could not believe that coal beds are the remains of up-rooted forests or shattered trees. Reeds and ferns afforded most of the material and they grew not far from the place where the coal is found, as is shown by the state of preservation. The vegetable matter was reduced to a pasty condition, elaborated in the tepid waters of the primeval globe and was deposited in a semi-fluid condition where now found. The proof of this hypothesis is found in the great extent of very thin coal beds, the parallelism of the opposite faces, in the existence of narrow fissures filled with coaly matter, as well as in the homogeneous substance and texture and the cubical division in coal beds. The conversion of the buried matters into coal might continue ripening during many ages by percolation.

MacCulloch²³ devoted many years to actual investigations in both field and closet, the results being given in numerous brief papers. The outcome of his completed studies is presented in an elaborate discussion of the origin of coal and the formation of coal beds.

Peat, lignite and coal form a continuous series, the transition being sufficiently perfect. The character of the plants, the presence of tree trunks, their bark converted into coal, show that the plants from which coal was formed were terrestrial, not marine. Those

²² A. Ure, "A New System of Geology," London, 1829, pp. 163-174.

²³ J. MacCulloch, "A System of Geology with a Theory of the Earth," London, 1831, Vol. II., pp. 311, 312, 336, 337, 339, 341, 359.

plants, being aquatic in type, grew in low moist forests in marshes on the borders of lakes or rivers. From the fact that peat occurs in only limited quantity within the tropics, he argues against the supposed tropical nature of the carboniferous plants. These embedded plants are so often in such state of preservation as to preclude the notion that they had been transported. MacCulloch's study of peat bogs led him to recognize four types. Marsh deposits are vast in area, uniting on one side with Lake deposits and on the other with Forest deposits, as they may be on either lowland or upland. They owe their origin chiefly to *Sphagnum palustre*. Two sets of plants aid in forming the lake deposits; shallow portions of the lake give floating plants, which, after flowering, sink to form a vegetable stratum; other plants fringe the pond, detain clay and detritus, supporting reeds and bulrushes; these gradually advancing form a marsh and eventually the lake is filled. The Forest peat contains submerged wood and is produced, for the most part, by plants after fall of the forest, so that it is a marsh peat. It is always forming in forests and the submerged tree-trunks are almost wholly in one direction, having been overthrown by the wind. Maritime peat is formed in estuaries by *Zostera marina*, which causes formation of sandbanks and bars; seaweeds may contribute even to shore peat, for *Fucus serratus* and *F. nodosus* are found in deep peat at some places in Holland. Transported peat is rare, occurring only in small quantities and as a fine powder; it is due to bursting of bogs. MacCulloch, after a detailed comparison of phenomena observed in peat bogs with those observed in coal deposits, concluded that by far the larger part of the coal deposits are now lying where the progenitor plants grew.

Mammatt²⁴ appears to have been the first to recognize that an underclay usually accompanies coal beds. "Seams of fireclay abound in the Ashby coal-field and there are very few coal-measures which do not rest upon it, as the sections will show." He remarks further: "From the circumstance, that so many cases occur, where a tolerably pure fireclay lies immediately under, and in contact with, a bed

²⁴ E. Mammatt, "Coal Field of Ashby de la Zouche," 1834, p. 73. Cited by H. D. Rogers, Assoc. Amer. Geol. and Nat., Boston, 1843, p. 454.

of coal, it may be inferred, that such clay stratum could not have been the soil, where grew the vegetable matter which produced the coal, unless this vegetable matter was a moss, a peat, or some aquatic plant; because in the clay, there is no appearance of trunks, or other vegetable impressions, beyond slender leaves, as of a long grass."

Lyell²⁵ about this time committed himself in part to both hypothesis, though evidently disposed to favor that of transport. "The coal itself is admitted to be of vegetable origin and the state of the plants and the beautiful preservation of their leaves in the accompanying shales precludes the idea of their having been floated from great distances. As the species were evidently terrestrial, we must conclude that some dry land was not far distant; and this opinion is confirmed by the shells found in some strata of the Newcastle and Shropshire coal-fields." The alternation of marine limestone with strata containing coal beds may be due to alternate rising and sinking of large tracts, which were first laid dry and then submerged again. He is clearly inclined to agree with the suggestion made by Sternberg and Ad. Brongniart, that the beds of mineral detritus were derived from waste of small islands arranged in rows and he thinks that the suggestion is supported by the observation that the Coal Measures flora is of insular type.

At a later period, Lyell accepted the autochthonous origin of the coal beds, as appears in the "Travels in America."

Buckland,²⁶ in 1836, accepted the theory of transport. "The most early stage to which we may carry back its origin was among the swamps and primeval forests, where it flourished in the form of gigantic *Calamites* and stately *Lepidodendra* and *Sigillariae*. From their native bed, these plants were torn away, by the storms and inundations of a hot and humid climate and transported in some adjacent Lake or Estuary or Sea. Here they floated on the waters, until they sank saturated to the bottom, and being buried in the detritus of adjacent lands, became transferred to a new estate

²⁵ C. Lyell, "Principles of Geology," 5th ed., 1st Amer. ed., Philadelphia, 1837, Vol. I., p. 134.

²⁶ W. Buckland, "Geology and Mineralogy considered with Reference to Natural Theology, Philadelphia, 1837, pp. 362, 353, 354.

among the members of the mineral kingdom. A long interment followed, during which a course of Chemical changes, and new combinations of their vegetable elements have converted them to the mineral condition of Coal."

On an earlier page, Buckland referred to the existence of erect stems in the Coal measures rocks: he was convinced that none of those recorded, aside from some near Glasgow, could have grown where they were found.

From this date onward the discussion respecting erect stems, became increasingly important. The facts and the conclusions are alike contradictory. It is better to pass by this matter for the present and to treat it apart.

Sternberg²⁷ did not accept the hypothesis that coal was formed from peat. He thought that one should conceive of a forest in the ancient time, when neither man nor plant-eating animals existed; that this forest grew for an indefinitely long period in a warm, humid climate; that the offal of buds, leaves, seeds, fruits and decayed stems accumulated on the ground; many generations of plants grew, one on the other, and so a mass, consisting of mold from wood, fruits, seeds, leaves, with complete examples of smaller plants, would be produced, whose surface would be covered with still living vegetation. Conceive now of a cataclysm, when a hurricane casts down the living plants and is followed by a flood, loaded with sand and mud—thus one has a true picture of the mode in which the overlying deposits of the stone coal are formed. Cases are rare where one finds erect stems of trees between two coal beds, losing themselves above and below in the coals.

The water-cover would hold the mold in place, would bring about decompositions and changes in the different materials and would cover the whole with clay and sand. It is unnecessary to borrow carbon from the air or water in order to get a coal formation, since in this interval, as well in the dry as in the wet way, humus and other acids, bitumen and coal itself have been produced, as occurs even to-day in peat bogs. The material existed in abun-

²⁷ K. Sternberg, "Versuch einer geognostisch-botanischen Darstellung der Flora der Vorwelt," Siebenstes und achttes Heft, Prag, 1838, p. 88.

dance and fermentation necessarily followed under the covering of water and sediment. It is unimportant to determine whether the water was fresh or salt.

In this way, he sees no difficulty in accounting for accumulation of stone coal deposits, even those of Saint-Etienne, which are 60 fathoms thick. He emphasizes the fact that the particular vegetation of the stone coal period produced colossal stems.

Link²⁸ was the first to study the texture relations of coals. He observes that two theories had been offered to account for the origin of coal beds; that of driftage does not commend itself to him, but that referring the coal beds to ancient peat bogs appears more reasonable. After summarizing the opinions of v. Beroldingen, de Luc, Steffens, Hutton and Leonhardt, he presents the results of his own investigations. Von Buch, feeling perplexed by some recent publications, had given him some specimens of coal from Bogota and had asked that he study them microscopically. The composition of one of those coals so resembled that of peat that he was led to a wide study of coals and peats from several horizons and regions.

In all peats, whether loose or compact, cell tissues form the body of the mass; the difference in quality of the peats being due probably to difference in the plants; the stone coals resemble peat in structure, some recalling the comparatively loose *Linum* peat used as fuel in Berlin, while others are more like the dense, almost wood-like peat from Pomerania; the Mesozoic coals vary, one from the Muschelkalk closely resembles peat, but the Liassic coals appear to be composed largely of woody fiber; the brown coal of Greenland is like the *Linum* peat, while that of Meissner in Saxony is similar to the dense Pomeranian material.

Link observes two quarto plates illustrating the vegetable structures observed in each of the peats and coals examined.

Logan's²⁹ notable memoir on underclays appeared in 1841. He

²⁸ H. Link, "Über den Ursprung der Steinkohlen und Braunkohlen nach mikroskopischen Untersuchungen," *Abhandlungen d. k. Akad. d. Wiss. Berlin*, 1838, pp. 33-44.

²⁹ W. E. Logan, "On the Character of the Beds of Clay Lying Immediately below the Coal Seams of South Wales," *Proc. Geol. Soc. London*, Vol. III., pp. 275, 276.

had found almost one hundred coal beds in the South Wales coal-field and, with rare exceptions, each overlies a clay bed from six inches to ten feet thick. The clay varies much in composition but it is a persistent deposit, so that coal beds which have thinned out in the workings have been found again by following the clay. Ordinarily, *Stigmaria* occurs abundantly in the clay and Logan thinks that plant was the source of most of the coal.

Soon after the field work of the Virginia and Pennsylvania surveys was completed, H. D. Rogers³⁰ gathered the salient facts bearing upon the origin of coal beds and presented them in a paper which has become classical. It bears the impress of the time, but it was based on broad observations by the author and his equally celebrated brother, William B. Rogers, aided by a corps of able assistants; the studies, lasting six years, were in detail for an area of somewhat more than 20,000 square miles, but in addition less detailed studies had been made in Ohio and Kentucky, so that the region under consideration was not far from 40,000 square miles. The discussion was the first serious attempt to account for the origin of the Coal Measures, which was based on actual study of a vast area.

At the outset, Rogers pronounced against any theory of delta formation, as according to his belief the Appalachian ocean deepened toward the west and northwest.³¹ The deposits are traceable coastwise for 900 miles, so that it seems improbable that fluvial currents could have assembled them.

The sandstones decrease in thickness and coarseness as they recede from the ancient shoreline at the east; the shales increase in that direction for a time and then decrease, while the limestones, wholly wanting near the shore line, increase in thickness and purity so as to become imposing before the Ohio River has been reached. The animal remains found in the limestones are marine. There

³⁰ H. D. Rogers, "An Inquiry into the Origin of the Appalachian Coal Strata, Bituminous and Anthracitic," Reps. of Amer. Assoc. of Geologists and Naturalists, Boston, 1843, pp. 434, 459, 463-467.

³¹ It should be noted here that when Rogers wrote the conditions on the west side of the Appalachian basin were not known; but does not affect the general argument.

were many alternate periods of movement and of total or comparative rest. Limestones indicate periods of comparative tranquillity. Some of the coal beds are of great extent. The Pittsburgh bed had been traced around an area of 14,000 square miles and there are isolated basins holding that bed far southeast from the main area, so that the Pittsburgh coal must have covered a surface of not less 30,000 square miles. The uniformity in thickness and the absence of abrupt variations are as remarkable as the area. These features "seem strongly adverse to the theory which ascribes the formation of such deposits to any species of drifting action."

The alternation of laminae of bright and dull coal; the lenticular form of the bright layers; the predominance of mineral charcoal in the dull laminae seem to be almost conclusive arguments in favor of belief that the vegetable matter grew where it was deposited. He finds it difficult to understand why the coal does not consist principally of the larger parts of trees if any drifting agency brought the materials together. The leaves and smaller parts would be detached before the trunks could become waterlogged.

But the beds have subordinate divisions, coal, clay, impure coal, so persistent in great areas that miners can recognize their bed at great distance from their own locality; only one method of accumulation can explain this. "I cannot conceive any state of the surface, but that in which the margin of the sea was occupied by vast marine savannahs of some peat-creating plant, growing half immersed on a perfectly horizontal plain, and this fringed and interspersed with forests of trees, shedding their offal of leaves upon the marsh. Such are the only circumstances, under which I can imagine that these regularly parallel, thin and widely extended sheets of carbonaceous matter could have been accumulated." The purity of the coal is inconsistent with any notion of drifting of the vegetable matter, "which according to any conceivable mode of transportation, would be accompanied by a large amount of earthy matter, such as abounds in all delta deposits and even mingles with the wood as in the raft of the Atchafalaya."

The underclay, irregular in structure, accompanies nearly every coal bed in the Appalachian basin and usually contains *Stigmaria*

ficoides with its fibrous processes. The roof contrasts with the underclay and is, normally, a laminated shale due to more or less rapid current and it contains vast numbers of plant impressions.

When the roof is sandstone there is evidence of tempestuous currents and the vegetable fragments are trunks and stems of large plants. Occasionally limestone forms either roof or sole of the coal bed but there is usually a very thin layer of calcareous shale parting them.

No hypothesis, thus far presented seemed satisfactory to Rogers, and he presented his own to account for origin of the Coal Measures.

He imagined extensive flats bordering a continent, the shore of ocean or bays, beyond which was open sea. The whole period of the Coal Measures was characterized by a general slow subsidence of the coasts, interrupted by pauses and gradual upward movements of less frequency and duration, and these merely statical conditions alternated with great paroxysmal displacements of the land. During gentle depression, the coast was fringed by marshes while arborescent plants were on the land side. The meadows would give pulpy peat; leaves blown in or moved by higher tide would rest on the peat; some would be buried and become pulpy, or, in some cases, by rapid removal of volatile constituents would remain as mineral charcoal. An earthquake comes. Water is drained from the swamps and their tributaries; muddy water draws from swamp and swampy forests leaves and the rest to distribute them with the mud over the bog. This is the laminated shale. The sea returns, rolls over the swamp to the dry land; withdrawing, it brings uprooted trees, and washed off soil, strewing the land stuff in a coarse promiscuous stratum. Repeated waves would add to the mass. The disturbance ends; coarse materials sink, then the less coarse and last of all the finest sediment, light vegetable matter and the buoyant stems of *Stigmara*, would sink together. A new marsh would be made and once more the savannahs would be clad with vegetation. This he terms the paroxysmal theory.

Petzholdt³² found two questions involved in the problem; were coal beds formed during a brief period and were they formed *in situ*

³² A. Petzholdt, "Geologie," Zweite Auflage, Leipzig, 1845, pp. 413-417.

or from transported vegetable material. The answer to the first question is certain—a great period of time was required for formation of the coal beds and their associated strata; but the second question is more complex and he is inclined to believe that both methods are possible, though there may be difficulty in determining which prevailed at a given locality. Vertical stems are not decisive, for they are found at times in rocks formed by transport, while prostrate stems occur in deposits clearly made *in situ*.

He believed that there were no continental areas during Carboniferous times, that the dry land consisted only of islands. For this reason, it is impossible to accept the hypothesis that coal was formed in great lakes or at the mouths of rivers. The only method of formation by transport would be the driving of great masses of vegetable matter against an island, which would collect in the quiet eddy on the opposite side, where, becoming waterlogged, they would sink and be covered with mud. He clearly prefers the doctrine of origin *in situ*.

An island, heavily forested for an indefinitely long period, becomes covered by a mass of bark, wood, etc., and similar remains of small plants. If the island be flooded by the outburst of granite and consequent elevation of the sea-level, the vegetation will be prostrated. By frequent outbursts the sea-level will be raised permanently and the island remains submerged. Deposits of sand and mud bring the island again to the surface of the water; a new forest rises on the grave of the old one. He thinks the alternation of strata and the formation of coal *in situ* can be explained very simply in this way.

Murchison,³³ after his study of the Donetz field in Russia, was convinced that the doctrine of transport alone could explain the conditions. The sections in southern Russia show “that the hypothesis of the formation of coal beds by masses of vegetation which there grew having subsided *in situ* (the truth of the application of which to some basins we do not deny) cannot be applied to the cases in question any more than to the pure marine coal beds of the northern districts, Northumberland and the northwestern parts of York-

³³ R. I. Murchison, “The Geology of Russia in Europe and the Ural Mountains,” London, 1845, Vol. I., pp. 112-114.

shire, etc.” Limestones with marine fossils are found at various horizons in the Donetz section. The presence of an underclay proves nothing—even though *Stigmaria ficoides* be the only plant present for a confused assemblage of plants is seen above and below the coal beds and the fossil beds are exclusively marine. The fine underclay indicates only that the sea bottom was covered with detritus of plants washed in by floods; the heavier earthy matters, accompanying the detritus, sank to the bottom, while the plants floated and formed the upper stratum. Those plants, thus left on the muddy slime, were covered afterwards by other sediment. Much of the coal, in strata alternating with marine sediments, may have come from the washing away and sinking into the sea of floating masses of matted earth and plants.

At a later date,³⁴ he discussed the question more broadly. He refers to the terrestrial conditions exhibited in the Upper Carboniferous of England and to the lack of a physical break there between the Lower and the Upper Measures, such as appears in Germany and France. In those countries, the later accumulations may well be accounted for by depressions of low woodlands and jungles beneath freshwater, followed by elevations and depressions. There is no physical break in Britain, but there is the same passage from marine to terrestrial conditions, of which the coal beds offer positive evidence; for the roots of *Sigillaria* are found in the underclay, which was the soil of a primeval marsh or jungle. The view, which supposes many and successive subsidences of vast swampy jungles beneath the level of the waters, best explains how the different organic masses became so covered with beds of sand and mud, as to form the sandstone and shale of such coal fields. But this theory of oscillations . . . can scarcely have an application to those other seams of coal, which, as before mentioned, are interstratified with beds containing marine shells, the animals of which, such as *Producti* and *Spirifers*, must have lived in comparatively deep water.”

He conceived that the latter class is to be explained only by the supposition that great rivers, flowing through lowlands, transported vast quantities of trees, etc., entangled in earth, and de-

³⁴ “Siluria,” 3d ed., London, 1859, pp. 315–317.

posited them on the bottom of the estuaries, or that vast heaps of organic matter were carried as floating masses to the sea. The Northumberland deposits, large tracts of Scotland, as well as the Donetz field in Russia offer fine proofs of these conditions. There were at least two modes in which coal measures were formed, one terrestrial, the other subaqueous.

Goeppert³⁵ in his elaborate work on the formation of coal beds gave the results of many years of study in the Silesian coal fields. A large part of the volume is devoted to determination of the materials forming coal; it will be considered in another connection. The chapter on the formation of coal beds is supplemented by a mass of illustrations drawn from the coal fields of Silesia, the whole discussion being so compact, so free from unnecessary detail that to make a just synopsis is difficult. The standpoint in Goeppert's work differs much from that in the discussion by Rogers, the only preceding study with which it can be compared. Rogers knew little about the intimate structure of coal itself and reasoned wholly from stratigraphical conditions; Goeppert was a skilfull palæobotanist as well as stratigrapher.

The important question for Goeppert is, were the coal beds formed of plants growing in place or of plants brought in from other localities.

There were many islands, mountains, valleys, rivers, etc., in the Coal Measures time. The organic matter was deposited on plains which were covered with sand, clay or mud. The extent of the deposits, their occurrence as plains or as basins show that they were laid down on the sea-bed, on slowly changing coasts or in enclosed sea or lake basins. The few marine products found in coal beds do not favor the opinion that the coal-forming material was collected from distant places and deposited in the depths of bays; everything indicates the utmost quiet; the vegetation covered

³⁵ H. R. Goeppert, "Abhandlung eingesandt als Antwort auf die Preisfrage—"Man suche durch genaue Untersuchungen darzuthun, ob die Steinkohlenlager aus Pflanzen entstanden sein, welche an den Stellen, wo jene gefunden werden, wachsen; oder ob diese Pflanzen an anderen Orten lebten, und nach den Stellen, wo sich die Steinkohlenlager befinden, hingeführt wurden?" Amsterdam, 1848, pp. 119-131, 136-139, 141-160, 278, 279.

the low-lying horizontal sea-strand. Changes of level, elevation and subsidence, led to burial of the plants under the ocean; sand and clay were deposited on the plant covered surface; dunes were formed, on which plants grew to run the same course. Through repetition of this process, the different beds were formed, separated by sand and clay. The conditions were like those of the present day, for submerged bogs and forests have been observed at many places along the coasts of Europe and America.

Well preserved stems are wanting because the plants lacked a dense interior structure. Filled stems are rare in Tertiary deposits because the trees were dicotyledonous; whereas they abound in the Coal Measures because the loose interior structure decayed quickly. Plants grew in these hollowed stumps; Goeppert found *Lepidodendron*, *Calamites* and ferns in decayed *Sigillaria*; in the stump of *Lepidodendron* he found the stem of a new genus, two feet long and vertical.

If the coal had become compact or if the quiet were undisturbed, the boundary between coal and the succeeding deposit is sharply defined; at most one finds only impressions of stems lying upon the upper surface. This latter condition occurs frequently in Upper Silesia, where the coal is composed chiefly of *Sigillaria*. It is quite true that filled stems occur even within the coal itself; Goeppert found them. He explains their presence by supposing that clay and sand were brought down by floods before consolidation of the coal, before the spaces between the stems had been obliterated by compression. In the same way he accounts for Brandschiefer or bituminous shale; the influx of muddy waters caused the alternation of laminae of bright coal, containing 2 per cent of ash, with dull layers, containing much mineral charcoal and 20 to 25 percent of ash.

The overlying beds were deposited after complete formation of the coal bed and the time-interval between the two deposits is as variable as the intervals interrupting the formation of a coal bed itself. Partings in coal beds show how the time required for different types of deposits may vary. A parting, ten inches thick, may be equivalent in time to a sandstone deposit elsewhere, many fathoms

thick. Perhaps one may regard layers containing great abundance of plants as equivalent to deposits in which the plants do not form beds, because in the latter case the plants were brought in contemporaneously with the sand and mud masses. He is convinced that the coal and the enclosing sandstone or shale beds are wholly independent deposits. And this belief is strengthened by the fact that the material, filling stems in coal, clay or sandstone, differs from that which surrounds them—an additional evidence of the extreme quiet prevailing during deposition. Goeppert was the first to recognize that the coating of the filled stems is the converted bark. The roots of *Sigillaria* and *Lepidodendron* were feeble, as are those of related plants to-day, and the trees were overthrown easily; and thus it happens that the stems, as in Upper Silesia, contribute to the formation of the coal. When overthrown, their cellular interior was squeezed out and converted into coal, as is seen near Dombrowa. All the phenomena indicate that the coal deposits were made during conditions of quiet, which would be impossible unless the plants grew where the coal is found.

The vast extent and constancy in structure exhibited by coal beds is important. He cannot think that such a mass could be floated in at once, yet how could it be deposited so regularly by any other means? He agrees with Lindley and Hutton and with Burat that the mass is too great for transport. He is unable to believe that the coal was the product of forests, because the amount is so vast; but the evidence satisfies him that the plants have not come from a distance. He prefers to accept the opinions presented by v. Beroldingen, De Luc, Ad. Brongniart, Link, and to believe that, if not all coal beds, at least the thickest originated as peat bogs—the more so because of the resemblance which a buried peat bog has to a coal bed.

He conceives that on the damp floor there grew lycopods, calamites, ferns, stigmaria and other plants, corresponding to the cryptogams and monocotyledons of present day bogs. Tree-like *Sigillaria* and *Lepidodendra* grew on the borders of the bog and at times were uprooted by floods. He laid great stress on the preservation of the plants, as precluding the possibility of transportation; he finds the mode of decay of tree stems equally important, for the conditions observed in *Calamites* are the same with those found in his experi-

ments with *Arum*. The presence of vertical stems is noteworthy because they are so numerous. It is possible for floods to carry away whole trees and to deposit them in vertical position; that occurred in the great débâcle near Martigny in Switzerland. This explanation would suffice for an isolated instance; but the number of such stems in the Coal Measures is too great; the analogy is in submerged forests of our own day.

The distribution of plants, both vertically and horizontally, has an important bearing on the subject. At one locality the flora may consist almost wholly of one species and at another, almost wholly of another species. There is a group-like distribution, so to speak, a social occurrence. In Upper Silesia, the coal may be termed *Sigillaria* coal, while in Lower Silesia it is *Stigmaria* coal. He asserts that an observer, in viewing the coal bed, involuntarily thinks of a peat bog.

Lyell's volumes on his second visit to the United States appeared at this time and had material influence in moulding public opinion. They will be cited in another connection.

Naumann³⁶ recognized the distinction between deposits formed on the sea border and those in fresh-water lakes, as had been done by Elie-de-Beaumont and Burat. The former contain, especially in their lower portions, rock layers with organic remains corresponding to the marine mode of formation, while the latter, less extensive, have no traces of marine fossils or anything else to show co-working of the sea. These types he terms *paralisch* and *limnisch*. These terms are equivalent to pelagic and mediterranean of Elie-de-Beaumont, to *terrains houillers de haute mer* and *terrains houillers des lacs* of Burat. The coal deposits of Great Britain, Belgium, Westphalia, Russia and America are *paralisch* or pelagic; those of central France, Saxony and Bohemia are *limnisch* or lacustrine.

The prevailing rocks of the Carboniferous are conglomerate, sandstone and clay shale, which occur in *paralisch* and *limnisch* alike. They are derived mostly from destruction of other rocks and their materials were transported. The land consisted not of small low-lying islands but mainly of great islands and continents

³⁶ C. F. Naumann, "Lehrbuch der Geognosie," Leipzig, 1854, Vol. II., pp. 451, 452, 571-580.

with mighty rivers, along whose coasts and in basin shaped depressions was deposited the vast system of sand and mud strata: This at length became marshland, offering the ground for the luxuriant vegetation of the first coal bed. In the Appalachian region, there may have been the flat coast of a land extending far to the east, from which great rivers carried sand and mud into the shallow sea at the west, in which, farther away, limestone was forming. Processes such as those now seen in the Nile, Mississippi, Hoangho and other rivers, continuing for many thousands of years, would raise the sea bed until it reached the water surface as a wide-spread marshland. Similar operations were going on in freshwater basins of the dry land leading to the formation of morasses, supporting *Calamites*, *Sigillaria* and other Carboniferous plants, which would give a deposit of peat.

The alternation of a great number of coal beds with thick masses of sandstone and shale is not so easily explained as is the origin of the first coal bed. The causes in paralisch areas are different from those in limnisch basins.

Lyell, Lindley and others held the opinion that seacoasts, on which paralisch deposits were formed, underwent slow subsidence during Carboniferous time. If one suppose that this subsidence was interrupted periodically, we have a mechanism by which the formation of successive coal beds could be explained. A similar result would be secured by occasional elevations of the sea-bottom, according to Petzholdt's conception. There is necessary in each case a general rise of the sea-level to cover the plant deposit with the sandstone and shale needed to give another swampy surface. This alternating subsidence and stability of the sea-bottom explains why the shale, covering coal beds, encloses a mass of plant remains and also why paralisch territories may have many but thin coal beds.

This explanation is not wholly satisfactory for limnisch areas, since one can hardly suppose that all of those could have suffered the repeated subsidence. One must conceive that between longer periods of stability there were epochs in which increased fall of inflowing streams or a diversion of flow occurred. The greater carrying power of the streams would bring the plant deposit and

at length form a new surface on which vegetation would begin once more. This would give a smaller number of beds. The, at times, great thickness and the frequent irregularity of coal beds in limnisch areas may be explained in part by supposing that they were not formed wholly as peat deposits, but received masses of upturned vegetation, swept out by floods, and this leads to the question of the formation of a particular coal bed.

There are two theories, transport (*Anschwemmung*) and *in situ* (an Ort und Stelle). Both may be correct. The great beds, beyond doubt, are of *in situ* origin, but there are many deposits which can be explained only by transport of plant masses.

It is known that streams bring down astonishing quantities of plant material; that ocean currents carry driftwood far and that it accumulates in vast masses on shores. Currents of the olden time must have been similar. If the widespread masses were buried under sediments, they would be transformed into coal beds. Neumann thinks that repetition of this process at mouths of streams in lakes or on the sea-coast would give a system of strata like the present series of coal beds with intervening sandstones and shales. Such drift masses are irregular in extent and thickness, often as blocklike masses. Such transported material would give conditions like those observed in coal beds of some limnisch areas, great irregularity and variation in thickness, breaking up into separate benches, some of them excessively thick. He thinks that under especially favorable conditions a coal bed might be formed in this way which would resemble one formed *in situ*. He considers also that this theory of transport explains many regular coal beds, such as those between limestones or other strata distinctly marine, as well as beds resting directly on granite, limestone, etc., without an underclay. He agrees with Murchison that in some cases the transport theory has value.

But for the greater part of the coal beds, the *in situ* theory must be accepted; their material was produced by vegetation an Ort und Stelle. All beds continuous over great areas, with regular and not too great thickness and with a *stigmaria*-filled underclay are to be explained in this way. But one must not think that there were real forests, which were thrown down in place, compressed by in-

coming sediments and changed into layers of plant material. The Carboniferous was not a tree and forest flora; it was morass and strand vegetation, developed on great emerging plains of marshland. The prevailing forms suggest that formation of the widely extended coal beds was analogous to the formation of peat bogs.

The purity of coal substance, the continuity of the beds, their regular thickness, the arrangement in benches due to clay layers produced by inconsiderable inundations, the upright plant stems and all the remaining relations of most coal beds appear to find sufficient explanation only in this or a similar conception of the mode of their formation. When at length a permanent elevation of the sea-level comes, the bog is buried under sand and mud, in whose first layers, just as in the last conditions of peat vegetation, a great mass of plant remains is found, torn from the neighboring land; so that it is clear that the roof shale of a coal bed encloses as a rule a large number of isolated plant remains.

Newberry's³⁷ attention was attracted to the cannel and semi-cannel of Ohio at the beginning of his studies. Observations made in peat bogs of this country and Europe led him to believe that cannel was formed in lagoons, where completely macerated vegetable tissue, probably parenchyma for the most part, accumulated as vegetable mud. Among other arguments favoring his hypothesis, he urges that cannel is more nearly homogeneous than cubical coal; that it contains more volatile matter, with more hydrogen, and must have been deposited in a hydrogenous medium which prevented oxidation; that it contains aquatic animals, so abundant at times, as to prove that they inhabited pools in which cannel was a sediment; that the plant remains in cannel are usually skeletonized; and that in open water lagoons of modern peat marshes, fine carbonaceous mud accumulates, which when dried is very like cannel.

Le Conte³⁸ compared the peat bog and estuary theories. The arguments in favor of the peat bog theory are, the purity of the coal, the fine preservation of the tender and more delicate parts

³⁷ J. S. Newberry, *Amer. Journ. Sci.*, 1857. A synopsis of this paper with some additional notes was given by him in *Geol. Survey of Ohio*, Vol. II., 1874, p. 125.

³⁸ Joseph Le Conte, "Lectures on Coal," *Ann. Rep. Smithsonian Inst.* for 1857, Washington, 1858, pp. 131-137.

of plants, the position of these plants in the roof shale, the completely disorganized condition of materials in the coal, the presence of the underclay, with roots and the occurrence of vertical stems rooted in the underclay. The chief objection to the theory is the repeated alternation, in the same locality, of coal seams with marine and freshwater strata. There being as many as one hundred coal seams, it would appear as though the same spot has been raised above water level and had been depressed below it at least one hundred times.

The estuary theory was proposed to avoid this difficulty. As an estuary at the mouth of a great river is occupied now by salt- and again by fresh-water, it should contain alternating deposits of marine and fresh-water origin. In seasons of freshet, the salt water is pushed out and the river water, loaded with mineral detritus and timber rafts, makes its deposits; during low water, the sea returns and marine deposits follow.

Le Conte finds insuperable objections to the latter. He thinks that coal beds were formed as peat bogs at the mouths of large rivers. The analogy is to be sought, not in the bogs of Ireland, but in those of the Mississippi delta. He supposes a vast delta, with spaces protected by fringes of plants from influx of river muds. There pure vegetable matter would accumulate until during some violent flood the barrier would be broken down and the whole space covered by mud. The delta, like that of the Mississippi, subsided slowly and the covering of mineral detritus eventually became ground for a new marsh. If the subsidence were more rapid than the river deposits could overcome, the sea would take possession and limestone would be formed. There is no necessity for conceiving repeated upheavals and depressions. "Coal has almost certainly accumulated *in situ* in extensive peat swamps at the mouths of large rivers, upon ground which was slowly subsiding during the whole period."

Lesquereux,³⁹ after long study of peat bogs in Europe, came to the United States, where as palaeobotanist to several official sur-

³⁹ L. Lesquereux, Palæontological report on fossil flora of the Coal Measures, Third Ann. Rep. Geol. Survey of Kentucky, Frankfort, 1857, pp. 505-522.

veys, he examined coal beds within a large part of the Appalachian and Mississippi coal fields. His first report upon the work in Kentucky is prefaced by discussion of matters relating to the origin of coal beds as illustrated by conditions in the Appalachian basin.

Bog plants are partially immersed and ordinarily are woody. The trees are mostly resinous and are such as can thrive only in bog conditions. The Coal Measures plants are ferns, clubmosses, horsetails, reeds and rushes, in character much resembling the forms prevailing in modern bogs. The peat of the Great Dismal and Alligator swamps rests on white sand and fills the depressions, while its surface is covered by canes, reeds and shrubs; where there is a cover of water, the soft black mud supports cypress and magnolia, and a great mass of material is added each year. Some ponds were once covered with vegetation, now sunken, as in Lake Drummond, which has at its bottom a forest, probably carried down by its own weight. He found similar phenomena in Sweden, Denmark and Switzerland. The water, to permit formation of peat, must have a constant level and be stagnant. The clayey bottom of bogs was made by fresh-water mollusks and infusoria or by *Characeæ* and *Confervæ*. Peat always has this mud.

Comparing these conditions with those prevailing in the Coal Measures, Lesquereux finds: (1) The fireclay varies in thickness, color, composition and in the quantity of *Stigmaria*; sometimes no coal rests on it—the soil was ready but conditions did not favor accumulation. Yet fireclay, without coal at one place, is likely to bear coal elsewhere. (2) The coal varies abruptly in physical and chemical features, just as peat varies in all directions, horizontal and vertical; and these variations depend largely on the plants concerned as well as on the amount of foreign matter introduced. (3) The roof shales, usually very fine, are evidence of slow subsidence, sometimes without marine invasion, as shown by plant remains; sometimes with marine invasion, as where the shales contain shells of brackish water type. (4) The limestones, equivalent to or continuation of the shales, need quiet deep seawater. Influence of the sea is very distinct in erosions due to currents. (5) The sandstones were due in many cases to turbulent waters, as appears from the

erosions and the mighty erect trees. The sand may have been derived possibly from dunes such as those on the Rhine or Elbe.

Lesquereux knows of no peat composed of fucoids and marine plants.

Jukes's⁴⁰ contribution to the discussion is not less important than those by Rogers and Goeppert, as it is the first presentation of the transport theory based on careful observation in an extended area. It covered the ground so thoroughly that little aside from detail or local coloring has been added since its publication.

Two opinions exist respecting the origin of coal beds; the first is that trees and plants were drifted into lakes, estuaries and shallow seas, where, becoming waterlogged, they sank to the bottom and became covered by the other accumulations; the second is that the plants were not drifted but grew and perished on the spot where they have formed the coal, just as our peat bogs would form coal if long buried under a great mass of earthy matters. While he does not purpose to range himself as an advocate of either opinion, he finds difficulties in the way of the latter which make him hesitate to accept it exclusively. These, observed in the South Staffordshire coal-field, he gives in detail.

1. The "rolls," "swells" or "horsebacks," which are ridge-like accumulations of clay rising sometimes eight feet above the floor, cannot be explained if the coal were formed at or above the level of the water; but if coal and "swell" alike were formed under water no difficulty exists.

2. The "rock faults" in the Thick coal. These are of two kinds. One, which he has not seen, is due to erosion of the coal after deposit, the hollow being filled with the material deposited on the coal. The other comes from contemporaneous deposition of silt or sand with the coal, so that they alternate at short intervals. The coal encloses cakes, layers or masses of sandstone, more or less intermingled with it. One such "fault" seen by Jukes, was 286 yards wide and it had been followed 400 yards without reaching the end. The upper part of the coal bed passes over the sandstone. At the

⁴⁰ J. B. Jukes, *Memoirs*, Geol. Survey of Great Britain. "The South Staffordshire Coal-field," 2d ed., London, 1859, pp. 34-42, 44-49, 201-206. The writer has not seen the first edition, published at least ten years earlier.

lateral border, both coal and sandstone split up so as to interlace. The condition is precisely similar to a cake of sandstone in clay. Jukes asks, if the sandstone was deposited in water, why not the coal also, for they are interstratified. The partings of sand in coal beds are of the same type. The laminæ of coal are obviously laminæ of deposition; their arrangement and their alternation with films of shale or with thicker partings of clay or sand would all be explained by the gradual deposition of laminæ and strata of different kinds of substances and by different degrees of mingling at the bottom of some body of water.

3. The extreme bifurcation of some coal beds; and here are phenomena extremely perplexing from the standpoint of the *in situ* theory. The great bed near Dudley, known as the Thick coal, is composed of numerous benches, each with its own persistent peculiarities. At two miles north from Dudley there are eleven benches, with 36 feet 6 inches of coal and 2 feet 11 inches of partings; while at one mile east from Dudley, there are thirteen benches with 28 feet 7 inches of coal and 1 foot 9 inches of partings. But at two miles east of north from Dudley, the upper two benches, there known as the Flying Reed coal, are at 84 feet above the Thick coal; at two miles farther, the interval has increased to 204 feet, while an intercalation of 10 feet appears midway in the Thick coal below. The benches retain their distinctive features throughout. Similar conditions prevail toward the west, where the interval between the Flying Reed and the other portion of the Thick coal increases from almost nothing to 128 feet within barely three miles.

There is a higher bed known as the Brooch coal. It is 95 feet above the Flying Reed, where that bed is 10 feet 6 inches above the Thick; but where the latter interval becomes 115 feet, the former is only 30 feet. Thus, while the Brooch and Thick are rudely parallel, the Flying Reed is oblique between them.

The normal section persists in the central southern part of the field to some distance south from Dudley; but toward the southwest the Thick coal breaks up, loses its structure and becomes worthless; toward the southeast, the bed thins out, has little good coal and is troubled by "rock faults" or "cakes of sandstone."

An additional difficulty is found in the expansion of the Thick and other coal beds toward the north. The expansion of the whole series and the splitting of the beds in that direction seem incompatible with the idea that the coal beds were formed at or above the surface of the water, while the intervening strata were deposited under it. Of the intervening rocks, those of coarse material are heaped up usually and thin out rapidly in all directions, while those of fine material have a greater area. This is true of superimposed beds forming a group; when material is fine, the disappearance of a bed is gradual. This law of area and thickness means only that fine materials were spread over a larger area "in consequence of their comparatively light specific gravity, or at least of their being more easily and therefore more widely transported by water, and being more generally diffused through it before finally coming to rest at the bottom. It was pointed out before, too, that beds of coal so far from forming any exception to this general rule, are its most marked example at the one extreme, while coarse sandstones and conglomerates form the most striking example at the other. . . . I wish merely to say as the result of an experience of a good many years, confirmed by the particular instance under examination, that the phenomena of the lamination and stratification of beds of coal, and their interstratification and association with other stratified rocks are explicable *solely by the relation of the specific gravity of their materials to the action of moving water*, and the consequent diffusion of their materials through the mass of that water."

The materials of the clays and sandstones were most largely deposited on the northern side of the coal field and sometimes failed to reach the southern part of the area, whereas the coal beds "were diffused equally, or at least more equally, over the whole area." He finds in the Bottom coal bed a notable illustration of these conditions—and it is only one of many. One "cannot fail to be struck with the obvious 'delta-like' or 'bank-like' form which the Coal Measures of South Straffordshire must have originally possessed, and the perfect resemblance they must have had to an undisturbed subaqueous accumulation. It seems to me then impossible to suppose otherwise than that the whole series of the Coal

Measures, coals included, were deposited by one connected operation of the same forces acting in obedience to the same physical laws on similar but slightly differing materials, through an indefinite but immensely long period of time."

Dawson spent many years in investigation of the Acadian coal fields, but devoted his attention especially to the South Joggins region where exposures are almost complete in a section of more than 11,000 feet thickness. He visited that locality with Lyell in 1852 and 1853 and afterwards made detailed study of each coal bed as well as of each ancient soil, subjecting samples from all to careful macroscopic and microscopic examination. The results of his studies were given in several memoirs and the details were published in the second edition of "Acadian Geology." In his first elaborate memoir⁴¹ he called attention to the gradual passage from coal to the roof shales through laminæ composed of coaled leaves and flattened trunks, separated by clay. He expresses the opinion that erect forests explain to some extent the accumulation *in situ*. The sandstone casts of *Sigillaria* are enclosed in bark converted into caking bituminous coal, while remains of the woody matter remain as mineral charcoal at the bottom of the cast. A series of such stumps with flattened bark and prostrate trunks may constitute a rudimentary bed of coal, of which many occur in the South Joggins section. He is convinced that the structure of the coal accords with the view that it accumulated by growth and not by driftage and that accumulation was very slow. He regards *Sigillaria* and *Calamites* as the chief contributors to the formation of coal. The woody matter remains mostly as mineral charcoal, while the cortex and such other portions as were submerged gave the compact coal. This memoir is concerned, for the most part, with the origin of coal.

In a later memoir,⁴² he considered especially the subject of accumulation. After describing the formations and the physical condi-

⁴¹ J. W. Dawson, "On the Vegetable Structures in Coal," *Q. J. G. S.*, Vol. XV., 1859, pp. 638, 640.

⁴² "On Conditions of the Deposition of Coal, more Especially as Illustrated by the Coal Formations of Nova Scotia and New Brunswick," *Q. J. G. S.*, Vol. XXII., 1866, pp. 95-104.

tions observed in the numerous coal beds, he presents these conclusions:

(1) The occurrence of *Stigmara* under nearly every bed of coal proves accumulation *in situ*; the sediments between the beds prove transport of mud and other materials, the conditions being those observed in swampy deltas. (2) True coal consists mostly of bark of *Sigillariid* and other trees, leaves of ferns and *Cordaites* with other débris, fragments of mineral charcoal, all grown and accumulated where they are found. (3) Microscopic structure and chemical composition of cannel and earthy bitumen as well as of the more highly bituminous and carbonaceous shales prove that they were fine vegetable mud as in the ponds and lakes of modern swamps. (4) A few underclays consist of this vegetable mud, but most of them are bleached by drainage. They contain not sulphide but carbonate of iron; rain, not seawater, percolated through them. (5) Most of the erect and prostrate trees had become hollow shells of bark before final embedding and their wood had been broken into cubical pieces of mineral charcoal; land snails, galley worms and reptiles were caught in them. There is much mineral charcoal on surfaces in all the larger coal beds. (6) *Sigillaria* roots have much resemblance to rhizomas of certain aquatic plants, but structurally are identical with cycad roots, which the stems resemble. *Sigillariae* grew on soils supporting conifers, *Lepidodendra*, *Cordaites* and ferns, which could not grow in water. There is remarkable absence of aquatic vegetation. (7) The occurrence of marine or brackish water forms is no evidence of sub-aqueous formation. The same condition is observed in the case of submerged forests.

The channels, sand or gravel ridges, inequalities of floor observed in coal beds are familiar features of modern swamps. The lamination of coal is not aqueous lamination; it is the superposition of successive generations of more or less decayed trunks and beds of leaves. It is very different from the lamination observed in cannels and in the carbonaceous shales.

The doctrine that coal is composed of the débris of land plants, though maintained by nearly all students, did not pass unchallenged. As far back as 1815, Parrott suggested that seaweeds had contrib-

uted materially to the formation of coal and, at a later date, Bischoff conceived that the Sargasso sea might yield a coal bed. Mohr,⁴⁸ in 1866, presented this view with great energy, and his opinions received more or less support from some eminent students.

Mohr contrasts stone- and browncoal, the one being fusible the other infusible. Land plants with much woody fiber yield charcoal, which soon decays when exposed to air and moisture. But seaweeds, river and lake algæ, having no fiber, decay to slime, which hardens through loss of CO_2 and CH_4 the original composition being that of starch and the allied substances. He combats Bischoff's assertion that *Calamites* and other land plants were concerned in forming coal, for the mass of the coal is amorphous and no treatment gives trace of plant skeleton. Evidently, everything with recognizable structure is a foreign body. Coal did not originate from land plants but from water plants, whose growth is protected from air and decay.

Only one of these water plants, a grass of wide distribution, is a phaenerogam; the genera and species of the others are very numerous and their mass is inconceivable. The Sargasso sea alone has an area seven times as great as that of Germany and none of its material can escape. Here is ample material; contributions from land plants are only accessory. The ash from sea weeds contains no clay; that from coal, lignite and peat consists of silicates not belonging to plants and contains clay. This material is derived from land detritus. The ammonia in distillates from coal is of animal origin; no accumulations in landlocked basins could have animals enough to supply this ammonia, but Darwin and Meyen have described the vast numbers of mollusks and other forms attached to seaweeds.

Sea plants are swept away, decay and sink or are distributed by currents. They are heaped up to great thickness, there being 338 feet of coal in the Saarbruck basin. Darwin saw immense masses of seaweed, floating, so constant in position that they are mapped as reefs and sand banks. If a layer of leaf coal occur, it is evidence only of material brought in from the land. The absence of

⁴⁸ F. Mohr, "Geschichte der Erde," Bonn, 1866, pp. 82-100, 130, 137.

animal remains in stone coal is due to the solvent power of carbon dioxide coming from the decomposing seaweeds.

Muck⁴⁴ came strongly to support of Mohr's doctrine in the first edition of his work. The essential objections to the theory are: (1) That great accumulations of seaweed are not likely to reach the bottom; (2) that remains of seaweeds have not been found in dredgings, which bring up only inorganic materials and animal remains; (3) the poverty of earthy materials in stone coal; (4) the absence of sea plants, and (5) the rare occurrence of sea shells in stone coal.

The answers to these objections are:

That the first is based on supposition, originating in lack of knowledge; that, for the second, it may be well to wait for its invalidation by opposing facts; as for the third, it stands in close connection with the second and so may be of narrowly conclusive value, but it is to be remarked that the ash-poor glance coal alternates with the often very ash-rich matt- and cannel coal, whose ash does not proceed from beds intervening between the coals, but is so intimately mixed with the coal stuff that it can be due in only small degree to later infiltration; as for the fourth, absence of sea plants is explained by the fact that those plants, in dead or torn condition, with or without access of air, undergo decay very quickly, becoming, within a few weeks or months, a structureless mass, in which organic remains cannot be recognized; the fifth is answered very easily, for animal remains are calcareous and are removed by carbon dioxide which originates during the coal making process.

In the second edition of his work, Muck, though no longer urging the theory, argued that sea plants, embraced under the trivial term "Tang," offered and do offer enough material for stone coal formation. The disappearance of organic structure in stone coal is explained as easily for seaweeds as for land plants by a kind of peaty fermentation. The morphological differences between seaweeds and the land plants corresponds to chemical differences in composition.

Petzholdt⁴⁵ gave a more than halting adhesion to this doctrine

⁴⁴ F. Muck, "Die Chemie der Steinkohle," Leipzig, 1st ed., 1880; 2d ed., 1891. The citations are from the second edition, pp. 162-165, 168.

⁴⁵ A. Petzholdt, "Beitrag zur Kenntniss der Steinkohlenbildung," Leipzig, 1882, pp. 25, 26, 27.

though without mentioning Mohr in connection with it. Referring to the current opinion that the material for formation of coal may be wholly or at least in great part derived from land plants, he says that this is evidently pure hypothesis, for remains of undoubted land plants occur in coal only under exceptional conditions. As, at the time when stone coal and anthracite were formed, the land was sunken, it is doubtful if the then production of land plants could yield the vast quantity required for the coal beds, he is led to look elsewhere for suitable material—and that, the sea plants appear to have produced. Remembering that the fauna of the Coal Measure time was marine and that, for these vast numbers of genera and species, the nourishment could come only from algæ, he asks with Bischoff, “where are the remains of the vast masses of sea plants, which since the Plant Kingdom first appeared on earth, have grown and then perished?” He replies that they have been consumed in forming coal and anthracite beds; and he is compelled to admit the conclusion that algæ, not land plants, produced the chief material for coal-making. At the same time, he is careful to state that this is only hypothesis, without direct proof, since remains of algæ are as rare in coal as are those of land plants.

Mietzsch⁴⁶ devoted much space to discussion of this hypothesis, which he regarded as baseless. His objections are those tabulated by Muck in the work just cited. In the concluding part of his argument, he points out that the Challenger expedition crossed the ocean along several lines and that the results of dredging leave uncertain whether seaweeds, after death, reach the bottom, become decomposed at the surface or become covered with animal remains. The Challenger expedition found no seaweed on the way to coal, though, several times it crossed the area, where, if ever, such deposits might be expected. Not only the petrography of coal but also the palæontology opposes the hypothesis. Seaweeds have not been discovered and the forms known in earlier days as fucoids have proved to be land plants.

Lesquereux⁴⁷ referred to Mohr’s hypothesis only to reject it.

⁴⁶ H. Mietzsch, “Geologie der Kohlenlager,” Leipzig, 1875, p. 244.

⁴⁷ L. Lesquereux, Ann. Rep. 2d Geol. Survey of Penn. for 1885, p. 104. Same for 1886, p. 465.

Seaweeds have cellular structure alone. They decompose quickly whether exposed to atmospheric oxygen or protected from it. They are soon transformed into a fluid, black material which penetrates the sands along the seashore. He thinks it possible that remains of marine algæ may have been thrown casually on swamps and that their decomposition products, added to those of the decomposing materials, may have enriched them and may have given cannel.

J. Geikie⁴⁸ sees in the alternation of coal and limestone, evidence of prevailing subsidence, while the coal seams indicate frequent recurrence of land surfaces. The cannels and iron-stones show that many wide lakes and lagoons existed. He finds lines and ribs of cannel associated with splint and even ordinary coals, while the cannel itself passes into common coal or black shale or even into black-band ironstone. The varying conditions are due to the mode of accumulation. Cannel was formed under water, for it contains fresh or brackish water fossils. The expanse of fresh water was surrounded by wooded flats; slimy vegetable mud, with, in places, ferruginous matter, was deposited where the streams entered. Along the shores were marsh plants, while farther back were trees and fern undergrowth. The last gave ordinary coal, the marshy plants were converted into splint, while the slime became cannel, oil-shale or even iron-stone.

Stevenson,⁴⁹ as the result of studies in the Upper Coal Measures (Monongahela) of Ohio and West Virginia, came to the conclusion that at the close of the Lower Barren Measures (Conemaugh) the northern part of the Appalachian area basin was a half-filled trough separated from the western coal areas by the Cincinnati fold. He accepted the *in situ* doctrine without reserve. The conditions observed in the Upper Coal Measures prove a succession of gradual subsidences interrupted by intervals of repose, during each of which a lid of coal was formed over all or part of the basin. The subsidence could not have been paroxysmal, for, as the shore line sank,

⁴⁸ J. Geikie, "On the Geological Features of the Coal and Iron-stone-bearing Strata of the West of Scotland," *Journ. Iron and Steel Inst.*, Vol. III., 1872, pp. 13, 14.

⁴⁹ J. J. Stevenson, "The Upper Coal Measures West of the Alleghany Mountains," *Ann. Lyc. Nat. Hist.*, N. Y., Vol. X., 1873, pp. 226-252.

the great marsh, which became the Pittsburg coal bed, crept up the shore—and this perhaps to the very close of the epoch. Thus it is, that though giving origin to many subordinate seams, the great bed diminishes westward. The Pittsburg coal bed began at the east and advanced westwardly. There is evidence in the distribution of sandstones and shales that a delta formation at the east pushed out into the basin, so that conditions favorable to coal-making existed first on the east side of the great basin. His summary is:

(1) The great bituminous trough west from the Alleghanies does not owe its basin-shape primarily to the Appalachian revolution. (2) The coal measures of this basin were not united to those of Indiana and Illinois at any time posterior to the Lower Coal Measures (Allegheny) and probably were always distinct. (3) The Upper Coal Measures (Monongahela) extended as far west as the Muskingum river in Ohio. (4) Throughout the Upper Coal Measures epoch, the general condition was that of subsidence, interrupted by longer or shorter intervals of repose. During subsidence, the Pittsburgh marsh crept up the shore, and in each of the longer intervals of repose it pushed out upon the advancing land, thus giving rise to the successive beds of the Upper Coal Measures. (5) The Pittsburgh marsh had its origin at the east.

Two years later,⁵⁰ after further studies in West Virginia, he offered additional arguments in favor of his suggestions and extended the scope of his hypothesis. The Appalachian basin at the beginning of the Upper Coal Measures was closely landlocked, communicating with the ocean at the southwest by a comparatively narrow outlet. At the east and southeast, rivers brought in their loads of detritus to be spread over the bottom of the basin; on the opposite side, few and sluggish streams flowed from the low Cincinnati fold. During periods of repose, deltas were formed and the marsh advanced on the newly formed land. If the period of repose were long enough to permit the filling of the bay, the marsh would extend across if begun on one side, or to the middle if passing out from all sides. The basin in West Virginia was never so filled with detritus as to permit coal beds to cross it. The Appalachian basin was never

⁵⁰ "On the Alleged Parallelism of Coal Beds," *Proc. Amer. Phil. Soc.*, Vol. XIV., 1875, pp. 283-295.

united with those at the west, anywhere north from Kentucky and he leaves to others to decide if there was at any time a connection farther south.

Still later,⁵¹ after very detailed studies in southwest Pennsylvania, he discussed the question Are coal beds continuous? He describes the Pittsburgh, Waynesburgh, Waynesburgh A and Washington coal beds as practically continuous in the northern portion of the Appalachian basin within Ohio, Pennsylvania and West Virginia—that is to say, that they are almost invariably present wherever their horizon is reached. But that is not true of the intermediate beds, which frequently are wanting in considerable areas; yet they are constant in many great spaces of from 100 to 1,000 square miles: he cannot resist the conviction that these beds are not in isolated patches but that for the most part these apparently separate areas are merely parts of a connected whole. The barren spaces mark localities which did not present conditions favorable to accumulation of coal. Respecting coal beds older than those of the Upper Coal Measures, he is convinced by the evidence of borings, that all, with possible exception of two, merely fringed the border of the basin.

Andrews,⁵² in rendering the final report upon his work in southeastern Ohio, presented the conclusions respecting formation of coal to which he had been led by his many years study of the Ohio measures.

The Lower Carboniferous detrital rocks were deposited in shallow water; the sandstones show ripple marks, striæ and branches of marine plants (the indefinite *Spirophyton*). Some conglomerate appears in the early part of the Coal Measures, but it is confined to the shore side of the basin and disappears eastwardly [toward the center of the basin]. Rocks exhibit rapid variations laterally; sandstones pass into shales; limestones into shales and sandstones. Some marine limestones, formed in shallow water, indicate, as do the coal beds, pauses in the almost continuous subsidence; but the great limestones of the Upper Measures [Monongahela] are to be considered merely as calcareous muds, for they vary as do the other mud rocks.

⁵¹ 2d Geol. Surv. Penn. Rep. KKK, Harrisburg, 1878, pp. 283-295, 301-303.

⁵² E. B. Andrews, Geol. Survey of Ohio, Vol. I., Part I., Columbus, 1873, pp. 345, 347-351, 354, 357, 358.

They were deposited in shallow water, for they are close to coal beds and show the shrinkage cracks due to drying.

Andrews adheres to the doctrine of accumulation *in situ*, asserting that his studies leave no room for any other conclusion. The vegetation grew on marshy plains skirting the ocean or perhaps making low islands near the shore. Slates as coal partings are of great geographical extent, holding the same stratigraphical position throughout, thus implying a temporary overflow of the marsh by ocean waters, with an even distribution of the sediment. Some beds contain evidence of tidal flows, for beachworn sticks, replaced by pyrite, lie in the coal as they were drifted upon the marsh. After complete submergence of the bog, trees growing on the surface were overthrown by turbulent waters; thousands of trunks of *Pecopteris arborescens* are seen in the roof of the Pomeroy coal bed, bent or broken down by the sediment-carrying water; and with them are great trunks of *Sigillaria* and *Lepidodendron*; while, in sandstone, drifted and buried trees from upland areas are not rare. The continuity of coal seams was often interrupted, as should be expected in great areas.

Andrews's studies were confined chiefly to southeastern Ohio and the adjacent portions of West Virginia, where the coal area approaches the central part of the basin, the original western border having been many miles beyond the present western limit of the Coal Measures. The irregularities of deposit are comparatively insignificant and the important members show a remarkable parallelism. He was led by the phenomena of his region to deny the possibility of notable variations in thickness of intervals between coal beds and he refused to accept as correct the great variations reported from the anthracite areas.

There are many evidences of erosion and planation during deposition of sandstones. The great bed on Sunday creek shows erosion from one foot to entire thickness of the bed, the overlying sandstone filling the trench and resting unconformably on the eroded edges of the coal. The eroded surface is smooth, there being no traces of rough work such as one should expect to find, if the coal were still soft and unconsolidated at the time of removal.

Andrews thought that cannel was originally vegetable mud. He emphasizes the abundance of *Stigmaria*, saying that they fairly reveled in this ooze. They, with their rootlets, abound throughout; their existence in these beds for hundreds of miles almost necessitates the conclusion that they are *in situ*. If they are roots of *Sigillaria*, those trees must have grown in the wettest portions of the marsh, which, in that case, could not have been lagoons. The *Stigmaria* are evenly distributed. If they had been drifted in, he thinks they ought to have gone to muck with the rest.

Newberry,⁵³ in the following year, discussed the origin of the various deposits composing the Coal Measures. The coarse rock underlying the series contains rounded pebbles of quartz, igneous and metamorphic rocks, with rounded and angular sand of the same material as well as cherty pebbles from the Lower Carboniferous. The pebbles for the most part must have come from Archean areas at the east and north; but he finds difficulty in explaining how material from those areas could be distributed in sheets at hundreds of miles from the only possible sources of supply. It is difficult to conceive of rivers as the transporting agency and he is inclined to find the explanation in the drift deposits of the Mississippi valley, ice being the transporting agent. Where the rock is coarse, fragments of the tree trunks, of *Calamites* and of roots are present, all broken, and sometimes heaped in masses covering several rods. Fruits, like *Trigonocarpum*, occur in hollow calamites and the mass is like driftwood, everything broken and battered.

The fireclays sometimes contain stumps of *Sigillaria* and *Lepidodendron* in unbroken connection with *Stigmaria* roots. Coal is seldom wanting above fireclay, though at times it has been removed by erosion. Coal beds were formed *in situ*. Fine sediment accumulated in pools and these were invaded by vegetable growth, to be filled up finally by bitumenized remains of generations of plants. Aquatic plants remove alkalies, phosphorus, sulphur and silica from the soils, as is seen in peat bogs, where the underclays are often fireclays. The varying deposits are explained by alternate elevations and depressions of the surface. Limestones were formed in arms of the sea and their presence is proof of unequal subsidence.

⁵³ J. S. Newberry, Geol. Survey of Ohio, Vol. II., part I., Columbus, 1874, pp. 104-115, 118.

Newberry opposed the doctrine that spores of cryptogamous plants are important constituents of coal. Sporangia and spores are common enough in American coals but they are an inconsiderable part of the whole.

Dana,⁵⁴ reasoning from chemical analyses, objected to Dawson's suggestion that coal was derived largely from bark or material of that nature. Though nearer coal in composition than is true wood, bark resists alteration longer and is less easily converted into coal. The occurrence of stumps and stems outside of the coal beds, "while proof that the interior wood of the plants was loose in texture and very easily decayed, is no evidence that those trees contributed only their cortical portion to the beds of vegetable debris. Moreover, the cortical part of *Lepidodendrids* (under which group the *Sigillarids* are included by the best authorities) and of Ferns also, is made of the bases of the fallen leaves, and is not like ordinary bark in constitution; and *Equisetæ* have nothing that even looks like bark. This cortical part was the firmest part of the wood; and for this reason it could continue to stand after the interior had decayed away—an event hardly possible in the case of a bark-covered conifer, however decomposable the wood might be. Further, trunks of conifers are often found in the later geological formations, changed *throughout* the interior completely to Brown coal or lignite." He appears to be convinced that the whole plant material contributed to formation of the coal, which he regards as the product of marsh accumulation.

Dawson⁵⁵ returned to the discussion in view of Huxley's assertion that spores are an important constituent of the coal-forming mass. Referring to his study of more than eighty coal beds in Nova Scotia and Cape Breton, he asserts that the trunks of *Sigillaria* and similar trees constitute the great part of the densest portion of the coal and that cortical tissues, rather than wood, predominate. Spores and spore cases, though often present abundantly, constitute only an infinitesimal part of the great coal beds. Sporangites or bodies resembling them are present in most coals, but they are acci-

⁵⁴ J. D. Dana, "Manual of Geology," 2d ed., New York, 1874, pp. 361, 362, 366.

⁵⁵ J. W. Dawson, *Amer. Journ. Sci.*, 1874. Supplement to 2d ed. of "Acadian Geology," 1878, pp. 65.

dental rather than essential constituents, more likely to be found in cannel and shales, deposited in ponds near lycopod forests, than in the swampy or peaty deposits, whence the coal beds proceed. While giving credit to Huxley and his predecessors for calling attention to the importance of spores in coal, he is compelled to maintain that they have generalized on insufficient basis, that sporangitic beds are exceptional among coals and that cortical and woody matters are most abundant. The purest layers of coal are composed of flattened trunks; other coals are made up of finely comminuted particles, mostly epidermal tissues—not only from fruits and spore cases but also from leaves and stems.

Mietzsch⁵⁶ attempted to answer the question, how did the vegetable material accumulate in great beds? Was it brought down by rivers from forest covered areas or did the plants grow where the coal is now found? The mode of occurrence can be explained measurably by either supposition; at times one process may act alone, at time it may be permissible to regard both as contributing.

He describes the heaping up of driftwood along streams as well as on coasts, whither it has been carried by currents; and he thinks that in this way may have originated some tertiary deposits of lignite, composed almost wholly of stems stripped of their bark. But many deposits of lignite and brown coal contain stems with bark, twigs, leaves and fruit preserved. The Suterbrander lignite of Iceland was formerly supposed to be driftwood, because of the present conditions in that land; but Heer discovered well-preserved buds, leaves and twigs of the plants, represented by the stems, which still retain their bark. The same criterion must be applied to the black coals. Many deposits of these and the greater number of brown coals have numerous tokens, rendering improbable, in part impossible, the supposition that they were made of transported plant masses. It is difficult to understand the regularity and vast extent of coal beds on the theory of transport, for driftwood accumulations are irregular and of small superficial extent.

The composition of coal tells against the theory of transport, for in most beds the ash is very small—surprisingly small, for in the process of coalification no part of the mineral content of the plants

⁵⁶ H. Mietzsch, "Geologie der Kohlenlager," Leipzig, 1875, pp. 244-257.

disappears, aside from soluble alkaline compounds. Some have found proof of transport in the composition of ash from stone coal, since it is quite similar to clay shale. But Mietzsch points out that living *Lycopodiaceæ* contain from 22 to 26 per cent. of clayey earth in the ash and asks why one should suppose that the older types were different. But if the coal contain an abnormal proportion of ash, there is reason to recognize influx of fine mud.

The fineness of the materials, clay and sand, in contact with the coal, proves a long period of quiet; and the same may be said of the plant deposits themselves. Such a period can hardly be accepted for rivers or for currents along coasts. The conditions of the underclay; the resemblance of the clay in many cases, as Steffens showed, to vegetable mould; the interlacing of *Stigmaria* roots like wicker work; and the occurrence of erect trunks are all opposed to the doctrine of transport. In most cases the conditions can be explained only by the doctrine that coal beds owe their origin to plants which grew where their remains are now found. He accepts the peat bog theory as advanced by v. Beroldingen and presents many facts as additional evidence in its support. The advance of bogs into lakes is proved by the discovery of pile constructions in Swiss peat bogs; along the seashore, algae form dense floating felts on which bog plants grow and the mass sinks to the bottom. Zeeland was once cut by bays much longer than now and part of the former sea-area is filled with peat. He strengthens his argument by many references to phenomena observed in the great swamps of Europe and North America.

In order to explain the origin of coal-bearing strata, holding a number of coal beds, one must distinguish between those formed along a coast and those formed along rivers or in the interior of an island or continent. Those of the first type are explained by the subsidence of coasts bordering on the North Sea. The preliminary work for drainage of the Zuyder Zee, as well as similar work elsewhere, has proved the existence of peat bogs in extended areas of shallow sea; anchor flukes have brought up peat from depths of 200 meters on the English coast. Such bogs become covered by river sediments and in case of long-continued slow sinking, the shallow sea area is filled, so that a number of bogs may be formed suc-

cessively. Among other illustrations, he refers to the discovery at Rotterdam of two bogs, 5 and 6 meters thick, separated by 4 meters of clay; to the presence of erect trees which, despite the long period which has passed since they sank below the water surface, are still standing on the sea bottom, partly surrounded by sediments; such trees on the coast of the islands of Sylt and Romo are of types which disappeared from that region many hundreds of years ago.

Changes in grade of rivers, caused by damming or by crustal movements, would lead to covering of bogs with sand or mud and to the accumulation of rock masses. He finds confirmation of this view in Livingstone's statements respecting the floods of African rivers and in the observations of others elsewhere.

Lesley⁵⁷ in prefaces to reports by geologists of the Pennsylvania survey, made frequent references to hypotheses respecting formation of coal beds. Ordinarily, he preferred to present the matter, as it were judicially, giving the difficulties in the way of accepting the hypotheses and leaving the decision to the reader. But in two of the prefaces he offers some important suggestions.

W. G. Platt described a little basin, barely a mile and a half across, in which three sections of Coal bed D were obtained. In all of them, the bottom bench is 2 feet 7 inches thick and composed of brilliant coal; but the upper part is a dull cannel or cannel shale, measuring 1 foot 3 inches, 8 feet 3 inches and 1 foot 2 inches, while between the last two the dip is about 8 degrees compared with about one degree elsewhere. A noteworthy feature is that while the ash in the cannel is from 21 to 25 per cent. and that in the pure coal below is only 1.6 per cent., yet the ratio of volatile matter to fixed carbon is practically the same throughout.

Lesley felt convinced that the petty basins, in which cannel was deposited, were waterways or pools and that more of them existed at once in certain horizons than in others. They were not due to erosion for the underlying coal bed is not cut out, it is merely depressed. There is no evidence of currents, for the mud is fine, the lamination perfect and the roof soft. The pools were almost stagnant. How could a depression come about to give, as here, a dip

⁵⁷ J. P. Lesley, Second Geol. Survey of Pennsylvania, Indiana County, 1878, pp. xiv-xviii; Lawrence County, pp. xix-xx.

of 5 to 10 degrees to an almost dead level bituminous coal bed? There is no room for suggestion of crustal movement as the area is too small; equally the cavern theory is excluded for no limestone underlies the horizon except at vast depth. He can see no explanation for most of the localities except in the subsidence of a floating bog, such as Lesquereux has described. On this the fine muds accumulated and the pool was filled.

He was led in this connection to consider the sequence of coal beds. If the Carboniferous plain consisted of a low area with shallow ponds, the coal forming vegetation would conform to the dimpled surface and there would be but one coal bed, intersected by river channels. This plain, if continuous, would be not less than 1,000 miles long by 300 miles wide [this refers to the Appalachian basin]. It is very difficult to account for the submergence of this continental plain to a depth of 50 feet below sealevel in order to give opportunity for formation of a second bed. Yet this "slow depression theory" may not be rejected easily, for without it, one cannot conceive how 20,000 to 40,000 feet of palaeozoic sediments could have been deposited; the more so, since many of the strata give every evidence of deposition in very shallow water. As a partial alternative, he suggests that the relative sea level may have been changed by the filling of basins. The effect of deposits by great rivers and that of glaciation are discussed but no conclusion is reached.

In the preface to the Lawrence report, he attempts to explain the origin of underclays. A peat bog and even a lake invaded by sphagnous growth must have some water circulation due to percolation from the surrounding land and to evaporation from its own surface—but the movement would be very feeble and it could transfer only the finest mud, though in course of time the result would be important. Dry grounds are largely fine gravel with rounded quartz and feldspar grains; the feldspar is soluble, it follows the indraught and settles beneath the evaporating surface with its floating peat. If the peat area be surrounded by clayey land, the percolation would be at a minimum; the water supply would be from the surface and less muddy, so that the underclay would be less in quantity. It would appear, then, that when the margin was a tight clay, deposits

of calcareous type show that limestone must have been exposed within the drainage area.

The thickest underclays should belong to beds next or near above the great sandrocks and it is a fact that our great clay beds are near the base of the Lower Productive Coal Measures [Allegheny] and that the few important clay deposits high in the series have coarse grained sandrocks not far below them. A logical consequence of such conditions is that sandrocks geologically close to such great underclays should be purer, more open sands and gravels than others which had not been robbed of so large quantity of interstitial clay. If the surrounding land contained iron in its gravel, there should be ball ore in the fireclay—as is seen in the New England ponds surrounded by drift.

Davis⁵⁸ described a cannel deposit in Yorkshire, somewhat resembling that discussed by Lesley. The bed is thickest in the center and thins away in each direction, meantime becoming less pure and passing into bituminous shale at the circumference. The condition is due to in-floating of plant remains, which sank to the bottom of the pond. The marked interlamination of shales and their marked increase toward the border resulted from more rapid subsidence of the muds. In some places the pond was filled up; there the underclay has abundance of *Stigmara* and the plants growing in such places were converted into ordinary coal. Afterwards the whole mass was submerged and covered with black mud. The cannel is fine, close-grained, homogeneous, with conchoidal fracture, without planes of deposition and everywhere yields beautiful specimens of fishes.

Reinsch⁵⁹ undertook the microscopic study of coal. He prepared a great number of sections, subjected them to close examination and published his results in an elaborate volume with 95 plates. These exhibited the structure of the coal as well as numerous forms which seemed to be organized. Reinsch maintained that the coal

⁵⁸ J. W. Davis, "On the Fish Remains found in the Cannel Coal of the Middle Coal Measures of the West Riding of Yorkshire," *Q. J. G. S.*, Vol. XXXVI., 1880, p. 56.

⁵⁹ P. F. Reinsch, "Neue Untersuchungen über die Mikrostruktur der Steinkohle des Carbon, der Dyas und Trias," Leipzig, 1881.

substance originated, mainly, from marine plants of such peculiar form that they cannot be assigned to any group of known types. He created a new group for their reception, *Protophytæ*, of which he made seven divisions. Remains of land plants are of very rare occurrence. This hypothesis differs from that of Mohr in that the plants are microscopic.

Petzholdt⁶⁰ at once made a fierce critique of Reinsch himself, his methods and his results. Of the seven divisions of *Protophytæ* two are decomposition products, three are certainly inorganic, one consists of fragments of land plants and one is based on minute fragments of coal. The decomposition products, mistaken for organic bodies, are termed bitumen by Petzholdt, who thinks them the same with those discovered fifty years before by Hutton in his study of the Newcastle coals.

Fischer and Rust,⁶¹ following Reinsch's method, found not only yellow and reddish resin-like bodies in black coal, such as make up the great part of the Scotch boghead, but also small grains, showing wood structure, in anthracite. In the black coal, they observed spindle-shaped or serpent-shaped bodies, whose relations they could not determine. The English cannel from Lancashire is very rich in little resinous cylinders and, as far as richness in resinous matter is concerned, is intermediate between the Bogheads and the ordinary coals. These studies have an important bearing on investigations which have attracted much attention in more recent years.

Green⁶² says that it is not easy to see how light material, such as dead wood, could be spread out evenly over tracts of hundreds of square miles, so evenly that the deposit shows comparatively little variation in thickness; and it is equally difficult to understand how, in case the coal be composed of drifted materials, it could be so pure as we often find it. The water bringing the vegetable matter

⁶⁰ A. Petzholdt, "Beitrag zur Kenntniss der Steinkohlenbildung," Leipzig, 1882, pp. 23 et seq.

⁶¹ H. Fischer and D. Rust, "Ueber d. mikroskopische Verhalten verschiedener Kohlenwasserstoffe, Harze und Kohlen," *Groth Zeitschrift f. Kryst.*, Vol. VII., pp. 209-243. This has not been seen by the writer. Cited by Petzholdt and v. Gümbel.

⁶² A. H. Green, "Geology," Part I., Physical Geology, London, 1882, pp. 257-262.

would certainly carry also mineral matter. The coal and its ash may, both of them, be of vegetable origin. Logan's discovery of the underclay or Seatstone under nearly every coal bed was the first great step in the right direction toward solving the problem. Binney's study of an erect stump discovered by Hawkshaw near Manchester was the next, for there a *Sigillaria* with *Stigmaria* roots was rooted in a seat clay, while the stem was surrounded by rock. Many similar cases were discovered. The underclay was the old soil supporting plants which produced a layer of nearly pure vegetable matter. When the surface was lowered beneath the water, sand and clay were laid on top and the band of dead plants was converted by pressure and chemical change into a seam of coal.

When sinking ceased, the shallow water was filled up and a swampy plain was made. Vegetation spread out from the land and a second coal bed began to accumulate. This process repeated many times over gave a succession of sandstone and shale with coal beds at intervals. The great swampy expanses in the delta of the Ganges and Brahmapootra must bear close resemblance to the marshy flats in which the coal was formed. The nearest approach, however, is in the accumulations on the coast of Patagonia, described by Lady Brassey in "A Voyage in the Sunbeam"; "To penetrate far inland was not easy owing to the denseness of the vegetation. Large trees had fallen and, rotting where they lay, had become the birthplace of thousands of other trees, shrubs, plants, mosses and lichens. In fact in some places, we might almost be said to be walking on tops of the trees, and first one and then another of the party found his feet slipping through into unknown depths."

There are, however, deposits of subaqueous coal, derived from driftwood carried down and buried amid mechanical deposits, but they are irregular and are apt to be impure. It is probable that the patches of cannel coal mark sites of pools or lakes in which vegetable matter lay until it was macerated into a pulp. This passes gradually by increase of earthy admixture into well-stratified carbonaceous shale.

Green had already presented the same suggestions, though briefly, in his work on the Yorkshire coal-field published in 1878.

Grand' Eury,⁶³ in the first section of his notable memoir, gives the grounds on which his theory of transport is based.

When one makes minute examination of coal, he discovers that the plants have been broken up and the parts scattered; fruits and leaves are apart from the stems; the layers of the bark are separated and dispersed; the interior parts of the stems have disappeared and the flattened cortex alone remains. The woody portions of the stems have been dispersed as fusain [mineral charcoal]. Stems are split and torn, *Cordaites* leaves are imperfect, everything, bark or leaf, is broken up. He thinks that a great part of the tissues was transformed into a kind of vegetable pulp, which makes up most of certain coal beds. That this was not wholly fluid or homogeneous is evident, for one may distinguish some traces of organization with the microscope or even with a magnifying glass.

The disintegration of the plant organs occurred after death and its character puts aside all suggestion of violent action. All the evidence contradicts the supposition that the forests were ravaged by inundations; everything points to quiet, peaceable flow of water. Most of the material was decomposed in place and carried away piecemeal. The vegetable matter was not deposited in deltas within either the north or the center of France.

The preservation of stems reduced to their bark is not surprising, for there was little wood in trees of the Carboniferous; but the mineral charcoal is not so easily accounted for. It seems to be fossilized buried wood, dried in the air and not changed into coal. It did not originate through maceration, though after formation it may have been subjected to moisture, as is indicated by lack of sharpness in outline.

The vegetable disaggregation was rapid, mostly in air, and was completed in swamps before removal. The conversion into detritus and the quasi-dissolution were sometimes pushed very far at the base of damp forests and at the bottom of swamps. The Carboniferous forests were marshy and aquatic. The plants grew quickly, reached maturity and soon died. Growth had to be energetic in order to carbonize the bark so as to make the contraction

⁶³ G. Grand' Eury, "Memoire sur la formation de la houille," *Ann. des Mines.*, Ser. 8, T. i., Paris, 1882, pp. 101-122.

small in coalification. That the air was damp and warm is proved by the aerial roots of *Psaronius* and *Calamodendron*; and the heat of the climate appears from the dense resinous bark, which often dominated the wood. Strong light, great heat, excessive humidity, great marshes in which plants grew quickly and died, explain conditions not easily explained by conditions of the present time. The residues falling into the marshy bottom of the forest, underwent aqueous rotting; they were then transported to the areas of deposit, which preserved them from complete destruction.

Grand' Eury published much relating to this subject and in 1900⁶⁴ he summarized all the results of his long studies in a memoir presented to the geological congress.

He describes fossil forests *in situ*, which show that the Carboniferous plants, though arborescent, were forms of marsh-habit like those of the Dismal Swamp, the foot and adventive roots in the water, but the stocks and rhizomas creeping on the bottom. The forests were very local. Growing in stagnant water and fixed by few roots to the ground, they were destroyed by slight causes and the roots alone remained. This would give a "soil of vegetation" as described by Dawson—a feature as familiar at Saint-Etienne as in Canada.

Coal is stratified, evidently deposited under water. There is no evidence that roots ever traversed the parallel laminæ of which it is composed. The stocks and roots, descending in the roof, spread out on the coal but never penetrated it. This condition is constant and is due to the circumstance that slowly deposited vegetable matter, undergoing fermentation, is opposed to the introduction of roots, which, being unable to live in it, instinctively refuse to pierce it. Similarly there is no relation between stocks and overlying coal. Their roots are often enclosed in coarse twisted coal composed of overturned stems, with leaves, branches, which, however, is continuous with overlying laminated coal. The elements are the same in both and they are identical with those in the adjacent shales, so that transportation from a distance is impossible. There is then in some coal beds evidence of formation in place or almost in place.

⁶⁴ C. Grand' Eury, "Du bassin de la Loire," *Compt. Rendus VIII^{me} Congrès Geol. Intern.*, Paris, 1901, pp. 521-538.

But most of the material forming the beds was transported; yet all coals resemble that found almost in place and the parts, certainly transported, are identical with similar parts of the rooted stems. The materials were derived from marshy forests on borders of the basin, which doubtless succeeded those temporarily installed in the basin of the deposit which afterwards became a lake. At the foot of this forest was elaborated, as in peat bogs, the humus or fundamental material of the coal. The basin of deposit was much like the bottom of a morass, for the mud of coal beds often resembles the clay underlying peat bogs. The debris of plants falling into water on the borders of the marsh became stratified in its depths. Grand' Eury was convinced that by this hypothesis he had reconciled the opposing theories, for he has shown that certain coal beds were formed by concurrence of both processes, as in the sub-aquatic parts of some swamps.

The permanent swamps, where primitive peat was elaborated, were not exposed to deposit of mineral sediments, they remained uncovered and disappeared; so that very little of the coal formed in place remains. The researches of Renault and C. E. Bertrand on cannel and the fundamental matter of coal show that coal was not always deposited on lake bottoms under moving waters, but that it may have been formed in stagnant or quiet waters of swamps.

The coal was deposited slowly, not continuously and there may have been long periods of arrested growth. The concentration of fossil forests and soils of vegetation in and near coal beds proves for the thick beds a very long period. Additional evidence in this direction is found in the advanced decomposition of the rocks forming the roof, their new chemical combinations, their impregnation with carbon, showing that they had been long in contact with the swamp before being transported and deposited on the coal bed.

The basin of the Loire was subjected to orogenic movements. The fossil forests have irregular distribution both vertically and horizontally; great sterile deposits break up the continuity. The basin was deepening throughout the period of formation, but each important coal bed corresponds to an interval of stability. That the mineral materials were brought in by streams is shown by their

distribution. The granitic rocks of the northern portion thin toward the south and their rooted stems lean toward the south and south-east; but the micaceous rocks of the southern portion thin toward the north and the rooted stems lean in the same direction, sometimes strongly. These mineral deposits interlock as wedges. But the coal beds pass from one type of rock to the other, preserving well their distance and parallelism. Grand' Eury finds no evidence to support the delta-theory of accumulation in deep basins; every feature leads to the belief that the mass of rocks could accumulate only by means of a subsidence, equal and progressive from the clay bottom.

In a still later paper,⁶⁵ Grand' Eury shows that coals of all kinds are practically alike in origin.

Coal beds are deposits of allochthonous peats formed by an exuberant vegetation, loving water, whose detritus was carried from shores to interior of immense marshy lagoons, where barks, cuticles and the rest were stratified with ulmic substances under the water. Stipites or dry coals of the Secondary in France are clearly the same in origin with the coals. Mineral charcoal is so abundant in one of the Upper Cretaceous coals as to give a finely-stratified structure to the bed. The brown coals of the Tertiary resemble coal completely in mode of occurrence; they are composed of marsh plants, leaves of dry land plants being in small proportion. Lignite is wood-like in appearance though formed of red humus from plants; they show much variation, but the mass of the material is derived from marsh forms. The peats of lowland areas or marshy plains are allochthonous—they resemble almost all deposits of mineral coal.

Gruner⁶⁶ notes the ancient forest in the quarry of Treuil, which had been described by Alex. Brongniart many years before. At 100 meters lower and almost directly under the quarry, Gruner found in the Treuil mine twelve great trunks in a space of less than 10 meters square; their roots spread out over the coal but did not penetrate into it.

He cannot accept the doctrine that coal consists of transported material. The continuity and uniformity of coal beds make a serious

⁶⁵ C. Grand' Eury, "Sur la formation des couches de houille de stipite, de brownkohle et de lignite," Autun, 1902, pp. 123-132.

⁶⁶ L. Gruner, "Bassin houiller de la Loire," Paris, 1882, pp. 160-170.

objection. In the little basins of Saint-Etienne, beds can be followed 5 to 10 kilometers in one direction and 2 to 4 in another with little change. He thinks that a current capable of uprooting trees would tear away the soil and pebbles also, so as to give a mingling of trees and detrital matter.

As large streams carry much mineral material there should be an alternation of vegetable elements and mud—and this is found in coal beds where shale appears in thin layers between benches of coal. These shales or the nerfs of fine sandstone could be produced only by water-currents, by inundations of brief duration covering the debris on the surface or invading shallow basins in which leaves, etc., were deposited slowly. The two modes of accumulation went on simultaneously in the coal period as they do now in peat bogs. He does not assert that coal was the peat of palaeozoic times; the flora and the climate were different; but the mode of formation was the same. The plants of the coal epoch grew where their remains are found. He cannot accept Grand' Eury's theory, which opposes the doctrine of *in situ* accumulation because stumps and trees are wanting in the coal beds themselves. Grand' Eury maintains that the vegetable matter was transferred from the place of growth to the basin where the coal is found, but the distance was small.

Gruner maintains that the current would have brought more than leaves and stems and that it would have distributed its load unequally; he thinks it preferable to conceive of a marshland extensive enough to admit of a thick cover of vegetable debris over an area of several thousands of square kilometers—as one finds in the Nord basin. Grand' Eury emphasizes the absence of stumps and roots passing from coal beds to the mur. But at Saint-Etienne itself, Lyell and Gruner saw rootlets passing from the coal into the underclay and Gruner saw the same condition in the Batardes coal bed, where *Stigmaria* abounds in the mur. The absence of stumps in the coal is to be expected, because the soft tissues would be crushed quickly under pressure and all traces would be effaced; moreover, in the nature of the case, stumps would be only a small portion of the mass. A negative result of study does not prove that the plants

did not grow *sur place*. Since the rapid current, which piled sand around the forests of Treuil, did not uproot the trees, one finds difficulty in understanding how the waters so slightly agitated as to be able to draw off only leaves and twigs did not leave in place the stumps whose roots are seen to-day in the underclays.

The preservation of the underclay proves that the stumps were not torn out before deposit of the plant debris forming the coal bed. The clay shows no signs of erosive action such as are seen so often in the roof. The deposit of the clay is itself a proof that then had begun the long period of tranquillity, which continued during formation of the coal. He is convinced that it must be admitted as almost proved that the coal beds have come from a vigorous local vegetation, whose debris accumulated at the bottom of shallow stagnant water and probably, quite as often, on a damp but not flooded surface.

The intervening rocks are, in character, wholly similar to partings in the coal beds, but they were formed not by petty inundations but by strong currents of prolonged duration. The existence of these is proved by erosions as well as by the sands which covered the coal forests. The surface subsided at intervals, as shown by phenomena connected with the faults in the Loire basin. But the flora was not destroyed, for one finds forests or isolated trees in place, in sandstones at all horizons, their bark preserved as coal. The sands are evidence that the agitated water prevented quiet deposition of vegetable debris. That was destroyed or scattered afar.

Meanwhile, the sunken surface was leveled up and the depression was filled. A second marsh was formed above the first, now buried under a thick bed of sand or mud. If the deposit of sand, etc., did not exceed 30 meters, the conditions under which the new bed was formed might not differ from those of the earlier bed. But when the sterile interval attains great thickness, 100 to 800 meters, the period of depression was very long and before its close the flora had undergone modification. Thus it is that one finds successive appearance of varied types, so that classification of the Coal Measures by their flora becomes possible. Subsidence of the type here conceived has been observed in rocks of all epochs. Lament and

Degousie, in sinking artesian wells at Venice, found beds of lignite and carbonaceous clays at 40, 60, 100 and 120 meters from the surface.

Von Gümbel,⁶⁷ perplexed by the contradictory results presented in memoirs, undertook a series of systematic studies, covering all phases of the subject. His study did not concern itself with chemical or technical matters and had little reference to botanical relations. At the outset, it deals only with questions relating to the constitution of coals; it begins with examination of peat-like substances and advances, step by step, to anthracite and graphite; it ends with a discussion of the mode in which coal beds accumulated. In breadth of scope, this study excelled that by any predecessor; in compactness and precision of statement the memoir has rarely been excelled. Much of the earlier portions bear directly on questions respecting the transformation of vegetable matter into coal, a subject to be considered in a later part of this work; but some of his observations are so closely connected with the final part of his discussion that they cannot be neglected.

The method of investigation by means of thin sections did not commend itself to v. Gümbel, who preferred the method proposed by Franz Schultze. The broken coal was treated first with potassium chlorate and strong nitric acid, and afterward with ammonia, in order to separate the particles and to make the transparent portions more readily available. Absolute alcohol completed the preparation by removing coloring matters. He gives specific directions as to the use of the reagents and warns against the possibilities of error in the study.

This investigation led him to recognize that the whole series from peat to anthracite is continuous and of similar origin. All of the members are made up of combustible materials. "Stone coal consists, apart from the earthy admixtures, of parts of plants, which, changed into a coaly substance, have taken up into their empty spaces, as well as into the intervals between the plant débris, a humin-like or ulmin-like substance (carbohumín) which was origi-

⁶⁷ C. W. v. Gumbel, "Beiträge zur Kenntniss der Texturverhältnisse der Mineralkohlen," *Sitzungs. Berichten der k. bayer. Akad. d. Wissenschaften. Math.-Phys. Klasse*, 1883, pp. 113 et seq. The citations are from pp. 190-212.

nally soluble, but became insoluble, so that the whole is amorphous and apparently structureless." The taking up of this material is the *Inkohlungsprozess*.

Adjacent rocks, containing plant remains, may have contributed to this coalification by means of circulating waters. It is self-evident that this soluble material might be deposited by itself apart from any remains of plants, not merely as layers of a coal bed but also in cracks and fissures; but such layers of structureless coal could have contributed in only subordinate manner to the formation of coal beds.

The several types of coal, Glanz-, Matt-, Faser-, Cannelkohle and the rest cannot have originated under similar conditions. In considering these he takes the most complicated condition—where several varieties occur in the same bed. Three modes of explanation are suggested by the investigations: (1) Original differences in kinds and parts of plants; (2) differing conditions, chemical and mechanical, in which the plants came to contribute toward making the coal; (3) heterogeneous external conditions under which the transformation was completed.

Difference in material in the several types of coal appeared constantly during the study; bark, and woody parts along with leaves in Glanzkohle; abundance of leaf organs, especially of the epidermis layers and less abundance of hard parts in Mattkohle; constant recurrence of little balls, membranes, the spores of authors, in astonishing abundance with algae-like clumps in cannel-like layers; all proving a certain dependence of constitution on the character of the plant remains. It is clear that the condition under which the plant material was accumulated was of great importance. This is evident from the great amount of Faserkohle [*fusain*, mineral charcoal]. If this material result from decay in free air, as would occur in the occasional drying of the surface in peat bogs, one must concede that this process was of vast extent during the coal-making time. It is unnecessary to suppose that the great supply was swept in; it could have been produced as readily on the bog surface. Similarly the dismembered parts of plants, clods or flocks, and the rest belong to a stadium anterior to formation of the coal. The pres-

ence of plant remains in soil, in every peat bog, justifies us in tracing back in some degree, certain relations of coal formation to similar origin. Accumulation of cannel-like coaly substances cannot be explained otherwise. The tertiary gas coal of Falkenau, pyropissite and Lebertorf all consist of a similar wholly broken up mass of plant parts. External relations had much to do with the conditions. If inflowing water bring much mineral matter into a bog, the borders are impure while the main portion is pure. So a coal may be impure on the borders and pure in deeper portions of the basin. Even the character of the overlying rock may be important.

Passing from the composition of the coals, he considers the mode of accumulation; first of all, rejecting absolutely as without foundation, the doctrine that coal could have been formed in the open sea and from seaweeds.

Coal beds consist of alternating, mostly very thin layers, like beds of sedimentary matter; this, with the fact that they are associated in series with undoubted sediments, seems to afford proof for the opinion that coal beds originate as do other sedimentary strata, in contradiction of the so-called peat theory, which accepts the idea of an origin in place after the manner of peat bogs. If one confine his attention solely to this layer-like accumulation and make no further inquiry, the conditions appear so completely explained by the former doctrine that facts favoring the latter have no value. V. Gümbel thinks that the presence of upright stems is of comparatively little importance as a proof of autochthonous origin, since their presence is exceptional and it can be explained in several ways—by drifting, by advance of waters into swamp forests or by plant growths floating on the water.

A careful examination of the query as to whether or not the lamination of coal can be explained by anything except deposit of suspended matter, leads to surprising results, when extended to the newer coal accumulations. The Quaternary brown coal offers an instructive illustration of the mode in which the lamination originated. These have absolutely the same structure as that of stone coal beds. It is known positively that they owe their origin to peat-like swamps and that the clayey, sandy partings, which accompany

them, proceeded from occasional overflows. Coming down a step farther to the coal making of our own time and ignoring for the present the various local modifications of peat, one can recognize two distinct modifications; Autochthonous, that forming or originating in place, and Allochthonous, the sedimentary, due to deposit of plant detritus in pent up waters. The latter shows, of course, evidence of sedimentary origin, is more or less dense and homogeneous, contains much earthy matter and the plant remains are notably advanced in change. Often it shows lamination only on drying.

All kinds of peat have the lamination. In Moortorf there are often alternating layers, differing in color, density and composition; in Specktorf the structure is especially distinct. Peat then is not an unstratified mass and one cannot say that the lamination of coal places it out of comparison with peat. Close investigation shows so many similarities between the peat layers and those of some coals, that this kind of structure favors rather than opposes comparison of coal-making with peat-making. This lamination appears in the autochthonous peat, in the diluvial brown coal originating in peat and in the whole range of the brown coal formation. But one must remember that the coals were not all formed on the same model; that comparison with peat is only tentative, as modern peat is made from moss and swamp grasses, while in the coal time the deposits came from a wholly different moor and swamp vegetation.

The stone coal formation for the most part is to be regarded as an inland formation, originating in widespread leveling and subsiding of the land, in many cases on swampy lowland along the sea-coast, over which floods distributed materials, such as shale and sandstone. On the extensive but not high land of the Carboniferous time, waters were penned in great areas and became converted into morasses, where a luxuriant vegetation flourished. It is very probable that in occasional drying of the swamp followed by renewal of the flooding, one may find explanation of the alternating bright and dull coal. This does not exclude influx of broken and shattered plant stuff from the higher surrounding region; that might even have predominated in some localities and have been the basis for cannel and boghead. Even from the swamp vegetation itself, decay-

ing material might float away to deep water within the swamp, so as to be heaped into peculiar massive layers like cannel. Flooding of the plain and deposit of mineral matter checked formation of coal; but the swamp would be re-established and a second formation be made; or possibly for a long period only rock material might be deposited.

How far variation in the water niveau may affect the question is considered only so far by v. Gümbel as to let him warn against the conception that basins, now filled by a thick series of coal bearing deposits, were filled with water in like manner at the beginning. These bowls were filled very gradually; they must be thought of as filled temporarily by a relatively shallow pond of water, which little by little reached a higher level.

At times, marine remains occur in strata between the coal beds, a condition which seems opposed to the explanation offered. But this occurrence is due to the fact that the low swamp land was spread out near the sea and was exposed to invasions, so that remains of marine animals might be enclosed in materials originating on the land. Marine or brackish water forms might be enclosed in the coal deposit itself, if it were formed alongside an arm of the sea.

In general, coal beds are an autochthonous product of dead, broken and disintegrated plant fragments with only local and petty contribution of transported material of the same character.

Wethered⁶⁸ called attention to the fact that coal seams are not single beds, but are separated by partings into benches which may differ in quality as well as structure. Sometimes *Stigmaria* are present in the partings.

The Cannock Chase or Shallow seam, near Edinburgh, has in its upper bench, 1 foot 10 inches thick, the brownish layers composed of macrospores and microspores, while the bright layers, containing some woody tissue, are composed mostly of a structureless material which he terms "hydrocarbon" in preference to "bitumen." Whence this comes he does not know, but wood tissue may contribute to it. The middle division of the bed is very different, consisting almost wholly of "hydrocarbon" with very few spores.

⁶⁸ E. Wethered, "On the Structure and Formation of Coal," *Q. J. G. S.*, Vol. XI., 1884, *Proceed.*, pp. 59, 60.

It is possible that spores may have been there and that they may have been decomposed, but spores are much more resistant than is woody material. The main division has a great accumulation of spores but also a fair proportion of the "hydrocarbon." He concludes that some coals are made up practically of spores, others are not; the differences in benches of a coal bed are of this character. Harker, reasoning from the ornamentation of the spores, suggested that they may have come from a plant related somewhat to *Isoetus*.

In the discussion of this paper, Carruthers took exception to conclusions based on markings seen on spores. He knew of no reason for referring those spores to *Isoetus* or any other form of submerged vegetation. Spores in coal were discovered first by Morris; they are associated with *Sigillaria* and *Lepidodendron*; the coal was the soil for the vegetation, penetrated by *Stigmaria* roots of the plants. A *Sigillaria* stem, at the Leeds museum, filled with white sand, penetrated far into the coal in which it grew. Coal seams are remains of forests which grew on swampy ground. The macrospores were not composed originally of brown substance, they are merely filled with it.

E. T. Newton stated that some coals are certainly made up of macrospores and microspores. Dull coal contains spotted tissue; intermediate coal contains both forms of spores; bright coal is a brown substance, usually structureless, but in one case, known to him, it consists wholly of spores.

Dawkins had never found sporangia in coal though both macrospores and microspores are abundant. Coal consists of carbon and resin, the latter giving the property of blazing, which Huxley would attribute chiefly to the spores. With this conclusion, Dawkins agrees only in part. The carbon comes from decomposition of woody portions, but the resin from cell concretions in the living plant. Carboniferous forests grew on level alluvial tracts but little above the water level.

Dawkins,⁶⁹ discussing the geographical conditions in Great Britain during Carboniferous time described the mode in which the coal beds accumulated.

⁶⁹ W. B. Dawkins, "On the Geography of Britain in the Carboniferous Period," *Trans. Manchester Geol. Soc.*, Vol XIX., 1887, pp. 45-47.

Oscillations of level still continued as the north, but the land constantly encroached on the shallowing sea, the mud encroaching on the Carboniferous limestone and the sandbanks following the mud closely. Meanwhile "the terrestrial vegetation was spreading from the old Lower Carboniferous land areas over the new Upper Carboniferous marsh lands, from the mountains of Wales and from the other Lower Carboniferous islands, now uplands. These forests contributed in their decay, through many generations, the accumulation which now, compacted by pressure and subjected to earth heat, is familiar to us as a coal seam. Each coal seam represents a land surface, just as the sandbanks and mudbanks (sandstones and shales) above it point to submergence. The fact too that the coal seams in a given section are parallel to each other or nearly so, implies that the forests grew on horizontal tracts of land, just as the associated sandbanks and mudbanks, with marine or freshwater shells, prove that these horizontal tracts were near the sea level or within reach of the waters of a mighty river. We may learn also from the study of the isolated coal fields that this great horizontal tract of forest clad alluvia occupied nearly the whole area of the British isles in the Upper Carboniferous age, from the Scotch Highlands southward, the dead flat being broken only by the higher lands, the old islands of the Lower Carboniferous sea, which I have already described. It was indeed the delta of a mighty river, analogous in every particular to that of the Mississippi—a delta in which from time to time the forest growths became depressed beneath the water until the whole thickness (7,200 feet in Lancashire) was accumulated of coal seams and associated sandstones and shales. After each depression the forest spread again over the bare expanse of sand and mud piled up in the depression."

The great northern and western land, termed by Dawkins, *Archaia*, whence came this mass of mineral deposits, occupied the North Atlantic sea, stretching from the west coast of Ireland and the Scottish Highlands to the American continent. To this great land may be traced the pebbles and groups of pebbles found in the Lancashire coal seams, mostly quartzites, which probably were brought down in flood time in roots of trees from the shingle beach.

Williamson,⁷⁰ in discussing the characteristics of the great fossil in the Owens college museum, remarked that that specimen had removed finally all doubts respecting the relations of *Stigmaria* by showing that plant to be the root of *Sigillaria*. The roots divide only once and after division extend indefinitely. The stigmata are lacking near the stem because the roots increased by exogenous growth and the superficial portion with its rootlets was thrown off. The trees grew in swampy ground as the swamp cypress does in American swamps. The gymnospermous plants grew on drier ground. The particular tree under consideration must have been at least 100 feet high. When it died, decay continued downward to the point shown and then was checked probably because the lower portion was buried in sediment and protected from air. Thence decay proceeded very slowly until the woody tissue of even the root disappeared. Meanwhile, the surrounding rock had hardened and had taken a cast of the stem and roots. The surface sank beneath the water and soft sand filled the cavity; thus the roots have their original form.

Fayol, after spending many years in study of the basin of Commeny, published his results in a remarkable work, which is unexcelled as a record of detailed observation. This work presented the grounds on which, several years before, its author had based his theory respecting the formation of coal beds. The positive position taken in favor of the transport theory and the clearness, with which the observations were offered, caused a notable reaction in favor of the doctrine that coal beds are formed of transported vegetable matter. A year after publication of the work, Fayol gave a summary of the delta theory, as he termed it, at the summer meeting of the Geological Society, when several members of the society commented on the theory. This resume, being the later presentation, is the basis of the present synopsis.⁷¹

The theory is based on the laws of sedimentation, as observed in

⁷⁰ W. C. Williamson, "On the Fossil Trees of the Coal Measures," *Trans. Manchester Geol. Soc.*, Vol. XIX., 1888, pp. 381-387.

⁷¹ H. Fayol, "Études sur le terrain houille de Commeny," I^{re}. partie. "Lithologie et stratigraphie." *Bull. Soc. Min. Ind. St-Etienne*, 2^{me} Ser., XV., Liv., III., IV., 1887; "Résumé de la theorie des deltas et histoire du bassin de Commeny," *Bull. Geol. Soc. France*, 3^{me} Ser., XVI., pp. 968-978.

deltas. Mingled detritus brought in by streams forms a stratified deposit in the basin, where the beds may be composed of a single substance or of several. Those beds are inclined, irregular and of small extent in tranquil waters but less inclined and of wider extent in agitated water. The inclination may vary from 0 to 45 degrees; different portions of a bed may vary much in age, while beds at different levels may be contemporaneous. The total thickness of a deposit has no necessary relation to the sum of thicknesses of the beds which compose it, for a basin, 100 meters deep, may be filled with inclined beds which may have a total thickness of 1,000 meters; he gives illustrations of these conditions.

The little basin of Commentry is one of several isolated areas in a synclinal which is about 60 kilometers long. These are separated by granite and gneiss and the evidence shows that they were always separate. That of Commentry, 9 by 3 kilometers, contains only Carboniferous rocks, except at the northwest, where some Permian remains. The rocks are not disposed at hazard, but there are definite zones or areas, each with its own type of rock, and these areas, as it were, interlock laterally. Each contains detritus derived from a single locality, though there is a greater or less intermingling where the deposits interlock as overlapping wedges. The history of the basin is thus interpreted by Fayol.

A lake, 9 by 3 kilometers in area and 800 meters deep, was surrounded by steep mountains. Rainwater ate away the surface, digged valleys, carried to the lake pebbles, sands, clay and plant materials, by which at length the lake was filled. This was one of numerous lakes, depressions and alpine elevations on the central plateau of France. Sediment brought in by the streams was heaped up at mouths and formed deltas. The main stream at the northwest, the Bourrus, cut through the mica schist and reached the granite, the latter being found in the upper part of the delta. This delta has the steep slope, with pebbles, blocks, sand, clay and plant debris, all disposed in accord with the laws of delta deposit. A somewhat smaller stream, the Colombier, at the east, flowing over anthracitiferous beds and afterwards cutting back to crystalline rocks, formed another delta of similar type; while petty streams from the north formed

small intermediate deltas. Apparently nothing came from the south, where the waters found their outlet. As the deltas increased in size and approached each other, their elements intermingled.

The lighter materials, clay and plant, floated into a bay in the southeast corner, where they formed some beds of shale and coal, while in less degree, similar materials floated off on the other side of the Bourrus delta into the bay at the west, where, in like manner, deposits of shale and coal accumulated. Eventually the Bourrus delta divided the lake into two small ponds and in the larger were formed thin irregular lenticular beds of impure coal. At length the lake was filled up and streams began to destroy the coal formation. Disturbances set in afterward but they were not serious, for the Permian deposits are almost horizontal.

The facts to support this explanation of the origin of the beds, both mineral and vegetable, are presented abundantly in the great excavations. The walls show local faultings, thinning of *faisceaux* of beds, pebbles of coal are seen in several strata, a great lenticular parting, in part very coarsely conglomerate, occurs in the Grande Couche. This remarkable coal bed is only a few centimeters thick at the southeast outcrop, but it swells thence to 10 to 12 meters and retains that thickness along the outcrop for about 2 kilometers and a half, beyond which it becomes thinner and at length disappears. Followed down the dip, it decreases in thickness and disappears toward the depth of 350 meters. The outcrop resembles an open C and the interval from the outcrop to the old rock is 500 to 800 meters. Before disappearing at the west, the bed breaks up into six diverging branches. Two other beds, the *Gres noirs* and the *Pourrats*, are in contact with the great bed at the southeast but they diverge westward. Some lenticular deposits of anthracite occur at the base of the series in both bays.

Fayol made careful calculation of the quantity of vegetation which could be produced on the whole drainage area of the lake and asserted that enough be produced to give ten times the coal present—and this within the period of 17,000 years. This period is a maximum, corresponding to a very slow filling and to the minimum transportation of vegetable material. On the hypothesis of formation *in*

situ after the manner of swamps, he thinks a period of 800,000 years would be required.

Fayol's delta theory, then, is that the deep lake was filled gradually with material carried down by the streams; that this material was deposited according to its gravity, fine clay and vegetable matter being regarded as equivalents; the arrangement being that observed in deltas. It differs from the theory offered by Jukes by adding the suggestion of great original depth of the basin, a conception against which v. Gumbel had argued a number of years before.

The record of the summer meeting of the Geological Society was issued as a separate⁷² and it contains the discussions by several members. The doctrine as enunciated by Fayol was regarded by Busquet as applicable to the basin of Decize, by Nougarede as supported by much observed in the basin of Epinac, and by Bergeron as explaining the conditions observed at Grassesac and Decazeville.

Renevier⁷³ was not prepared to give assent to the doctrine and he suggested some grounds for hesitation. Vegetable materials in suspension are equivalent to fine mineral débris. If the coal beds were formed, as Fayol thinks, by the sweeping off of vegetable débris from the land and its deposition on the surface of the delta, that débris should accumulate on the border of the dejection cone, in the more tranquil waters, so that the deposit should have only a gentle original slope. But the great bed of Commentry has an extreme dip of 50 degrees, the same with that of the beds which accompany it. He regards these dips as impossible in a cone of dejection and suggests other modes of accounting for them. He maintained that the phenomena indicate, in part at least, the agency of marshy or semi-aquatic vegetation. Even the great thickness of the Grande Couche seems to him an argument in favor of vegetation in place, receiving increment brought in from the neighboring forests.

Delafond⁷⁴ was inclined to question the applicability of the doctrine without modification to the basins of the Saone-et-Loire (those of Autun, Blanzay and Creusot). Fayol conceived the existence, before the coal deposition, of a deep depression transformed

⁷² "Réunion extraordinaire dans l'Allier," *Bull. Soc. Geol. de France*, 3^m Ser., XVI., 1890.

⁷³ E. Renevier, "Réunion, etc.," pp. 77, 78.

⁷⁴ F. Delafond, "Réunion, etc.," pp. 73-78.

into a lake, in which would be deposited, in form of a delta, the various elements which constitute the Coal Measures; the plants, giving the coal beds, would have been furnished principally by the luxuriant forests which grew on the alluvial plains of the deltas. During and after the formation of the Coal Measures, the movements of the crust were so unimportant as to leave no apparent trace, so that to-day one can easily find all the circumstances accompanying the formation of the deposit. But these were not the conditions in either the basin of Autun or in that of Blanzay and Creusot. There were important movements of the crust during and after the Carboniferous and the Permian.

In Autun the successive stages overlap in such fashion as to be explained only by admitting, during the process of deposition, the existence of crustal movements which modified profoundly the shape of the basin. Further, it would be difficult to explain by this doctrine why in Autun the important coal beds are in only the lowest part of the formation, at the time when the alluvial plains of the deltas were small; whereas, in the later part of the formation when those plains should have acquired great extent and could support immense forests, there were formed only some insignificant deposits in the Upper Coal Measures. Similarly in the other basins of the Saone-et-Loire, there were movements during the formation of the Coal Measures and of the Permian, which caused the overlapping of deposits.

Delafond recognizes that the process of delta formation explains the manner of deposit, the separation of the various materials, coal, shale, sandstone; but the intervention of movements of the crust is indispensable.

De Launay⁷⁵ remarked that it would not be incompatible with the theory of deltas to believe that movements of the crust occurred during the period of the Coal Measures and that they had given progressively the great depth observed to-day.

Almost at once after the appearance of Fayol's first publication, de Lapparent⁷⁶ gave his adhesion to the new doctrine. His first

⁷⁵ L. De Launay, "Réunion, etc.," p. 102, footnote.

⁷⁶ A. de Lapparent, "L'Origine de la houille," Assoc. Franc. Avanc. Science. Conférences de Paris, 1892. The same in *Rev. des quest. scientifiques*, Juillet, 1892.

publication was in 1887; in 1892 he presented his views in vigorous fashion. The statements are made with that clearness and precision which characterized his writings, so that it is well to give the synopsis in detail.

The early observers regarded coal as due to transported vegetable materials but the fascination of actual conditions, as exposed by Lyell, led men to abandon that explanation and to see in the vast peat bogs of this day the modern representative of coal beds. De Lapparent gives a synoptical statement of the peat bog theory. He thinks this doctrine deserving of a double reproach—it draws no argument from the nature of the coal itself⁷⁷ and it does not consider sufficiently the topographical conditions of each bed.

De Lapparent says that coal, especially in the great maritime basins, has wholly mineral aspect, laminated, with conchoidal fracture and showing no sign of organization; even thin sections show only amorphous material with rare indications of cellular structure. In most cases, chemical and microscopical examination must be combined, but sometimes the former is unnecessary. Fayol discovered at Commentry, in 1883, lenticular brilliant zones which proved to be flattened stems. Grand' Eury, in 1876, asserted that the coal of the Loire basin was formed of vegetable remains laid flat in a position uniform enough to suggest a liquid in repose. Several beds at Saint-Etienne consist wholly of *Cordaites* bark and the Grande Couche at Decazeville is composed of bark of *Calamodendron*. This determination, first made by Grand' Eury, is interesting as showing that the leaves, barks, etc., play in the coal the same part that vegetable imprints do in the shale. The ulmic matter, resulting from maceration of vegetable detritus, formed the sediment in which the recognizable remains were buried.

To explain the origin of this amorphous material, he quotes Saporta, who relates graphically the conditions existing in the dense forests of the hot, humid Carboniferous time. The rapidly accumulating mass of leaves, loose internal material from tree trunks, was

⁷⁷ It is well to remark in passing that de Lapparent's statement was made 54 years after Link's investigations, 33 years after Dawson's publications in the *Q. J. G. S.* and 9 years after publication of v. Gümbel's elaborate researches.

converted into ulmic material, the lower part of the deposit becoming a blackish paste. Detached heaps of leaves, peripheral sheaths of ferns, cortex of *Sigillaria*, *Cordaite*s, etc., obstructed places at foot of slopes and awaited only the passage of waters in order to abandon to them the great mass of material in various stages of decomposition. This vegetable pulp is the amorphous gangue in which one finds the barks and leaves. But it is no longer in place. It shows evidence of having been suspended in water; the condition of the fragments shows that they have been subjected to frequent and energetic friction. By what mechanism was this transport effected?

Grand' Eury thought that the waters of great rains sweeping down the slopes drew the vegetable detritus into lagoons—such waters were limpid. At other times the streams carried muddy water with sand and clay giving sandstone and shale. Thus was explained the alternation of coal with other rocks. But de Lapparent cannot understand this selective process—the conditions are unlike those of the present day. The delta theory of Fayol is preferable and it applies perfectly to the lacustrine basins of central France. It is no mere hypothesis, but the result of long, painstaking observation in the great open quarries of Commentry. More, Fayol made experiments which proved that the conditions were such as must be due to delta formation.

The cause was gained and it remained only to answer objections offered by adherents to the old theory. The presence of vertical trunks was shown to be not only not inconsistent but rather consistent with the theory. And this was the most important objection. The presence of *Stigmaria* in the underclay is no objection. Those are rhizomas capable of giving origin to *Sigillaria*; when swept by torrential currents, they were drawn into the deltas, where being heavier they would pass to the bottom of the mass which was to become coal. The delta theory is full of important consequences. There is no further need of numerous and complicated movements of the crust. The beds have been deposited one on the other as sediments on the surface of a submerged dejection cone. If complete stability of the surface be one of the conditions of the phenomenon, there is at least no *a priori* reason to put it in doubt; as the beds had to be deposited

with a certain inclination, there is no need of calling in, for lake basins, dislocations to explain phenomena which may very well be primordial. The time required for the deposits is vastly shortened. Not only a complete coal bed, whatever its thickness, but also a portion of the underlying clay and sandstone, becomes before our eyes the product of a single flood. Fayol has shown also the rapidity with which vegetable matter is transformed into coal. The coal of pebbles in the rocks is coal, so that when a portion of the delta was exposed by a change in equilibrium of the surface, its coal suffered erosion as did the other rocks. De Lapparent finds in the study of Commeny some important matters bearing on the origin of the coal itself, which will be considered in another connection.

The coal of the maritime basins of France is a vegetable alluvium deposited in a delta; but the material has been brought from a greater distance and by the action of the waves it has been spread out over a greater area. In the central plateau the vegetable paquets descended violently from the neighboring steep slopes to be deposited *en bloc* with pebbles of the torrent, thus producing some thick but very localized masses of coal. In the Nord area, there must have been, far above the mouth, wide river sheets in time of flood, many kilometers broad, like the Amazon and Orinoco, on whose surface the vegetable matter was spread. In subsiding, the ulmic materials, which formed the chief mass, separated themselves from the fine clays. This explains the constancy of the floor, while the roof may consist of any material. As the unmacerated vegetable matters, fronds and barks, had to float on the surface of the ulmic materials, one can understand why they are so abundant in the roof. The mouth of rivers changed their position, which explains the invasion of brackish waters. Thus is understood easily the filling of the old arm of the sea.

Why is it that a theory, so luminous, has not gained the adhesion of any but Frenchmen? De Lapparent thinks the hesitation due to lack of confidence in anything novel which comes from outside, and tends to overthrow notions so long accepted that they seem to be part of a national patrimony. Foreign doctrines are subjected to quarantine as foreign goods at a custom house. It is possible that

the hesitation is due to imperfect exposition of the doctrine at the outset, when Fayol declined to accept crustal movements as having had any influence; but that error was corrected afterward by Fayol. De Lapparent considers that to deny all influence of orogenic movements upon even the lacustrine areas would be excessive. Coal basins are depressions, feeble lines of the earth's crust, are landmarks of fractures whose equilibrium has been disturbed frequently.

Malherbe⁷⁸ notes that, though the explicit statement is not made, Fayol evidently regarded his doctrine as of universal application. But Malherbe asserts that, while it may suffice for Commentry, it cannot suffice for other basins. He utilizes the Liege basin as testing ground. That basin has an area of 40 by 15 kilometers, with 50 coal beds and numerous petty seams. The northerly border is but slightly disturbed; away from that the disturbances become serious and some of the faults extend through the formation, which is 1,200 to 1,500 meters thick. This is very different from Commentry, which is small in surface and depth, enclosing an insignificant number of beds. If the Commentry strata are in the original position, those of the Liege basin must be the same; but everything proves the contrary—the enormous displacements of the beds, the presence of *Cardium* in horizontal and inclined beds alike; all show original horizontal deposit. The waters from the Liege basin carry salt and Roget-Laloy has proved the same for the coal formation of the north of France, concluding therefrom that that is the sea water of the coal time imprisoned in the rocks. The deposit is not lacustrine but fluvio-marine.

Fayol's capital objection to theories other than his own is the apparent impossibility of periodicity in deluges due to terrestrial oscillations. Malherbe thinks it equally difficult to explain by Fayol's hypothesis the transport of a mineral formation, 1,500 meters thick and enclosing 50 coal beds from 0.45 meter upwards on an area comparable with that of modern seas—for the elevations breaking the area into basins came after the coal time. Oscillations are known in the present time, they are probable for other times. If one recognize that subsidences necessary for formation of beds

⁷⁸ R. Malherbe, "Géologie de la houille," *Ann. Soc. Geol. de Belgique*, T. XVII., 1890, Memoirs, pp. 25-40.

occurred only during accumulation of the great beds and that the overflows, bringing about the deposition of sterile rocks, led to transportation of vegetable matter intercalated in the intervals as veinettes, the number of overflows would be greatly reduced. Malherbe discusses Fayol's doctrine in detail and at the close expresses much doubt respecting its competence to explain even the phenomena of Commentry.

Renault⁷⁹ says that coal beds are intercalated among beds of sandstone and shale and, like those, they have all the features of deposits made in water. In sandstone, the fragments are inorganic and preserve the chemical as well as the mineralogical characters of the rocks whence they came; in coal, they are derived from plants and conserve the anatomical, at times, also the chemical characters of the plant organs. The fragmentary condition of these organs, the small proportion which they form of the mass, consisting chiefly of a blackish vegetable powder as gangue, show that the plants had been subjected to repeated energetic friction before their burial. So one cannot admit that coal beds were formed solely by accumulation, *sur place*, of debris from an exceptional vegetation, spreading over marshes, lowlands, lagoons, etc., near lakes or the sea; that the surface, subject to elevation and depression, saw, checked and again restored, that great vegetation of which innumerable generations would be represented by successive coal beds.

The fragments of wood and bark are very small. If the vegetable materials had been changed into coal and buried where their debris is found, it is certain that, in place of these reduced fragments, there would be entire trunks, branches and complete leaves as principal constituents of the mass. More, taking into consideration the diminution of volume, which vegetable tissues experienced in becoming coal, it is evident that numerous forests of high trees growing successively on the same place, would form hardly a few centimeters of compact coal—even though one suppose that, at the foot of the trees, there grew a mass of herbaceous plants. Further, the thick coal beds are separated by great deposits of sandstone or shale; as those deposits were formed slowly after the

⁷⁹ B. Renault, "Études sur le terrain houiller de Commentry," Livr. 2^{me} Flore fossile, Saint-Etienne, 1890, pp. 704-712.

manner of sediments, one must assign, if he admit this succession, an extraordinary duration to the coal epoch.

Renault accepts the explanation offered by Fayol and commends especially the shortness of the time which it requires. During the Carboniferous time, the air held more moisture than now, as no ice cap covered the polar regions; the rains were frequent and abundant; depressions occupied by lakes were filled rapidly. If one consider the strength of the torrents, greater than now, and the vigorous growth of vegetation, surpassing that of the present tropical regions, he will recognize that the formation in the Basin of Commentary could have been deposited in even less time than is required by the Fayol hypothesis. The selection, so distinct in deposition in inorganic materials, would take place with equal readiness in the plant materials. Coarse fragments, such as trunks, branches, would be dropped with the sand and clays, while the lighter, finer materials would be carried beyond into deeper parts of the basin.

Erect stems have little bearing upon the question at issue. Many of them are merely in-floated fragments, while those, which are *in situ*, do not penetrate the coal beds and have no relation to them.

Spring⁸⁰ undertook investigation along a new line. His study, though bearing largely on the question of transformation, finds place here because the results have an important bearing on the manner of accumulation. The homogeneity, the structure and composition of coal beds all seem to favor the doctrine of transport; but the stratification within coal beds does not exclude the doctrine of *in situ* origin, for with rare exceptions modern peat bogs show a structure resembling that of coal. It is clear that a definite conclusion respecting mode of formation cannot be reached by study of the coal bed alone; he determined to investigate the shales of mur and toit.

The mur of a bed formed by transport would be impregnated with vegetable matter to some distance below the coal while the toit should contain little. In the Belgian terrane, the shales of the toit,

⁸⁰ W. Spring, "Détermination du carbone et de l'hydrogène dans les schistes houillers," *Ann. Soc. Geol. de Belgique*, XIV., 1888, "Memoires," pp. 131-154.

when broken up by atmospheric agencies, yield a hard rather plastic material, resisting plant growth, yet they are as black as those of the mur. The theory of origin from peat would require that, in the mur, the quantity of carbon increase as it approaches the coal, as it must contain roots of plants; while in the toit the carbon should decrease gradually as one recedes from the coal. There is no abrupt change from coal to shale in the roof, so that the latter should be richer in carbon than the mur.

It is necessary to see how transformation of vegetable matter into coal is explained by each theory. This necessity is felt by defenders of the transport theory, because the flowing water furnishes only a mass of wood, bark, leaves whereas according to the theory of peat bog origin, the change of vegetable matter into peat is associated with the deposition.

In passing from vegetable matter to coal, there is great loss in hydrogen and great enrichment in carbon. Either the plant materials were changed into peat, lignite and the rest successively, or the organic matter was converted at once into its present state without passing through the intermediate stages. The latter explanation rests chiefly on Fremy's experiments, which showed that vegetable matter, subjected to high pressure and a temperature of 200° to 300° C. for a long time, becomes converted into a material very closely resembling bituminous coal. A fundamental objection to this theory is that no evidence exists suggesting that any such temperature prevailed, and nothing is less established than the conception that time could compensate for deficiency in heat.

However this may be, it is evident that, according to the doctrine of transport, the change going on in materials between the shales requires that specimens of shale collected at equal distances in receding from the coal, should show the carbon and hydrogen varying in a determinate manner; in proportion as one recedes from the coal the shale should have less of carbon and more of hydrogen as the more volatile hydrocarbons would go farther. But the doctrine of peatbog origin leads to a contrary condition.

A determination of the carbon and hydrogen in shales near coal beds may aid in answering the question as to whether the

hydrocarbons are impregnations from the forming coal or are due, as in the coal itself, to transformation in place of vegetable debris, imprisoned when the shales were deposited. These determinations would tell us if one should prefer the doctrine of transport to that of formation *in situ*, and whether the transformation of vegetable matter into coal has been accomplished by a kind of distillation or has been caused by a special kind of fermentation.

In the course of his studies, Spring discovered an unexpected condition—that the shales, containing organic matter, were the seat of slow oxidation, depriving them of hydrogen. The shales not only protected the coal from erosion but also from oxygen, as gas or in solution, the action of the oxygen being exhausted in the shales. As the encasing rocks are not the same everywhere, the character of the coal should differ in the same bed and in different beds. Usually, meager coals are on the peripheral parts of a basin while fat coals prevail in the middle portions. May this be because the latter have been better protected against the action of oxygen?

The shale samples studied were from the Saint-Gilles mine near Liege, eight of them, with one from the coal bed. Five were taken from the toit and three from the mur, each representing a vertical space of a half meter. They are marked "a," "b," "c," "d" and "e" for the toit and 1, 2 and 3 for the mur. The material was dried and analyzed with these results;

	Coal.	"a"	"b"	"c"	"d"	"e"	1	2	3
Carbon	86.61	7.54	3.35	2.21	1.20	0.70	0.99	0.93	0.80
Hydrogen	4.65	0.79	0.62	0.54	0.56	0.59	0.84	0.53	0.58
Ash	1.84	98.33	92.05	93.86	92.00	94.08	95.16	93.50	93.20
Oxygen, sulphur } by difference }	4.80	3.34	3.98	4.10	6.24	4.63	3.01	5.04	5.42

The carbon varies greatly but regularly, decreasing as one recedes from the coal. No conclusions can be drawn from conditions in the mur as the quantity is very small, but the variation in the toit is a logarithmic curve, the cause producing the variation is in inverse relation to distance from the coal. This seems to show that Fremy's conclusions are right and that the shales were impregnated with carbonaceous materials at expense of the coal, the com-

pounds less rich in carbon going farther. But the relations lead to a chemical impossibility; "a" gives C_8H_{10} , while the coal gives practically $C_{16}H_{10}$.

The reason is that not all of the water of hydration goes off at 120° . To escape this error, Spring employed hydrofluoric acid and continued the solution until the ash was about 10 per cent., the same with that of many coals. Analysis of the residues gave these ratios;

	"a"	"b"	"c"	"d"	"e"	1	2	3
C: H	24.80	30.45	36	?	?	19.80	?	?

The results for "d" and "e" are uncertain as are also those for 2 and 3, the hydrogen being present in such small quantity. Determining the absolute relation of hydrogen he has

	Coal	"a"	"b"	"c"	"d"	"e"	1	2	3
Carbon	88.61	7.54	3.35	2.21	1.20	0.70	0.99	0.93	0.80
Hydrogen	4.65	0.30	0.11	0.06	?	?	0.05	?	?
C: H	19.09	24.28	30.45	36.00	?	?	19.80	?	?

The relation of carbon and hydrogen in the mur is very nearly the same as in the coal; it contains particles of coal little altered. But the toit results are remarkable; the hydrogen diminishes in relation to the carbon and in "d" and "e" it is no longer in appreciable quantity. Evidently the roof shales are not impregnated by volatile materials coming from the coal, as required by Fremy's theory. The transformation of the vegetable matter is rather by ulmic fermentation. Within the primitive marshy mass the plant substances have yielded ulmic materials while becoming richer in carbon. These have impregnated the whole and have been modified by external agencies.

The doctrine of transport seems to be out of harmony with the results as by it one would have difficulty in explaining the richness in carbon characterizing the toit. The alluvium, because of its physical nature, could not support a sufficient vegetation. If one suggest that the alluvium at its origin was mingled with much vegetable debris, it may not be superfluous to ask if the plants could remain on slopes, denuded and torn up by the flood which had swept away the most thoroughly rooted plants. Everything speaks of origin *in situ*. But returning to the analyses.

If the alluvium covering the peat bogs came gradually it would be mingled with a greater or less quantity of vegetables, which had to undergo the same changes as the underlying mass in order to become coal. One ought to find in the alluvium the same proportion of carbon and hydrogen as in the coal itself, or at least nearly so. If this relation do not exist, evidently some external influence has been exerted. And the relation does not exist; the variation increases as one recedes from the coal; this irregularity must be due to some slow action becoming appreciable through lapse of time. Everything seems to indicate that slow oxidation went on in the shales, acting chiefly on the hydrogen, for which oxygen has the greater affinity, so that it has converted the vegetable matter into anthracite in the more distant part of the shales.

According to this conception, coal with abundant gas could have been formed only when the material was protected against atmospheric agencies. The many varieties of coal owe their origin rather to unequal degrees of protection; the fattest coals give off the most abundant grisou—evidence that the enclosing rocks are impermeable.

Wild⁸¹ in describing the Lancashire coal-field, referred to the "bullions" which are characteristic of the Mountain-Four-foot coal bed. These, embedded in the coal, are ferro-calcareous "concretions" more or less pyritous, frequently enclosing mineralized wood, "showing the woody and cellular structure of the plants which have produced the seams of coal from which the concretions are extracted." Shells are absent, the nodules being for the most part fossil wood in varying degrees of preservation. The coal bed is persistent and its roof shale contains concretions, known as "baum-pots," which at times are embedded partly in the coal. These are ironstone or calcareous, sometimes weigh 40 pounds and contain marine shells but rarely any wood.

After a review of all the coal beds he considered the question of their formation. The generally accepted theory that coal comes from growth *in situ* seems to be a natural conclusion, for the roots in the underclay pass through several layers. It is true that under-

⁸¹ G. Wild, "Lower Coal Measures of Lancashire," *Trans. Manchester Geol. Soc.*, Vol. XXI., 1892, pp. 364 et seq.

clay is not essential for vegetable growth, but more than three fourths of the coal beds have it. The "bullions," composed of fossil wood, occasionally show rootlets working their way through the decaying wood, separating the fibers which now surround them. The fossil wood is often parallel to the bedding of the coal, a condition familiar in prostrate forests and in peat accumulations. Erect trunks and stems are unusual both in coal and peat. The underclay was the land surface which supported vegetation like the forests of swamps where warmth and moisture prevail.

If coal is to be considered as derived from drifted material, he is puzzled to discover what has become of the shells and fishes, which must have abounded in the tracts of water in which the deposits were laid down. To float some of the large trees either vertically or horizontally, with their outspread roots having a radius of 15 to 20 feet, would certainly require enough water to accommodate fishes and mollusks. Remains of fishes are not necessarily destroyed by embedding them in coal-forming material, and shells are as capable of resisting destruction as fish spines are. Shells and fish remains occur often in impure cannel. The "bullions" have yielded no shells, and fish remains are very rare in pure coal. That the trees were forest growth is proved by the splendid specimens in the Manchester and other museums.

Estuarial swamps with intermittent subsidence, permitting deposition of sand and mud, would explain alternations of coal and other strata, whichever theory of coal accumulation be accepted. Marine conditions frequently followed directly upon formation of a coal bed; fishes of shark-like types are in shales directly overlying coal at many horizons. But shells and fish are unknown in the underclay.

Orton,⁸² in his description of the coal-fields of Ohio, considers the various theories of formation; some of them appear to be based on merely local conditions, others are extravagant and only a very small proportion of the explanations seems to have been the result of careful observation in extensive areas.

In a coal-field, one finds a system which can be explained only by subsidence. Limestone is found above and below coal beds and

⁸² E. Orton, Geol. Survey of Ohio, Vol. VII., Antioch, 1893, pp. 256-262.

is accompanied by iron ore. The coal beds, though variable, are wonderfully persistent and are always associated with fireclay. There is no haphazard mode of occurrence. Coal is product of land life; limestone is of marine origin; the ore depends on life for concentration; sandstone, occupying the intervals between other rocks, is due to inorganic forces and it may be about equivalent to the others. Orton's conclusions based on more than twenty years of study in much of the Appalachian basin, are:

(1) The Ohio coal-field, at the beginning of the Carboniferous, was an arm of the sea with the Cincinnati arch as the western boundary. (2) Marginal swamps of varying width became the earliest coal seams by long continued growth and subsequent fossilization. (3) While the swamps were submerged, in succession, and covered by shale, sandstone or limestone, in turn covered by other swamps, the continental nucleus grew slowly at the south and the Cincinnati arch united with it by like advance eastward, expelling the waters of the gulf and converting the earlier formed portions of the coal formation into dry land. (4) Every coal swamp had a narrower area than its predecessor. (5) As all coal seams were formed at sea level, so all were raised by continental growth to an approximate equality, which their outermost outliers still retain. (6) To look for the earlier formed seams in the center of the basin would be to look for the living among the dead. (7) In the formation of one seam, in particular, the floor of the gulf, around which the swamps were growing, seems to have been raised nearly to sea level at many points, and coal appears to have been formed in island-like masses over much wider areas than any single marginal swamp would account for.

Bolton⁸³ describes a peculiar deposit of coal in Ireland. The Jarrow coal bed appears to be a great cake, attaining a maximum thickness of 16 feet and thinning in all directions except toward the west, in which direction no tests have been made. Underclay is absent at almost all localities. The lower part of the deposit is a smutty anthracite with slaty structure and containing abundance of

⁸³ H. Bolton, "Notes on the Plant and Fish remains from the Jarrow Colliery, Co. Kilkenny," *Trans. Manchester Geol. Soc.*, Vol. XXII., 1894.

Lepidodendron stems. The upper part is a pure typical anthracite. Fish remains, *Gyranthus*, *Megalichthys*, etc., occur throughout. The plant remains are *Halonias*, in the form of crushed cylinders of wood. This condition and the mingling of fish remains led Bolton to conceive that the deposit was due to the bursting of a lagoon-like swamp and to the discharge of vegetable debris, consisting of bottom accumulations as well as of the twigs, etc., on the surface. He refers, for illustration, to the bursting of Solway moss in 1771, which spread over a square mile of ground, giving a mass of vegetable matter, 30 to 40 feet deep, demolishing houses, overturning trees and so contaminating the Esk that no salmon ventured into the river during that year.

Kuntze⁸⁴ took up the discussion from a botanist's standpoint and advanced a wholly new theory. He antagonized v. Gümbel's conclusions which he maintains are wholly at variance with that observer's facts. His own studies from 1879 to 1883 had shown that the Carboniferous flora was sylvo-marine, a floating vegetation. The objection that marine forms are wanting does not hold good: the forms, described by v. Gümbel as resembling algae, are chitinous bryozoans related to *Aulopora*. These, as stated by v. Gümbel, occur abundantly in cannel and make up a great part of the boghead coals. Carboniferous coals contain much sodium chloride, one fourth to one half kilogram per ton; Tertiary coals contain none. It is certain that the Carboniferous coals are not allochthonous; the flora must have been marine.

He contends that students have failed to interpret *Stigmaria* rightly, for the appendices, regarded as rootlets, are water leaves. The *Stigmaria*, with intertwining rhizomas and hollow stems rising above the water, formed floating islands. When overloaded, they sank to the bottom and through the mud until checked by some harder rock. He agrees with Potonié's conclusion that they are not allochthonous but he cannot concede that the underclay or clay shale is a petrified humus, for the clay is no more a soil than are the granite and other silicious rocks with which coal beds are often in

⁸⁴ O. Kuntze, "Geogenetische Beiträge," Leipzig, 1895, pp. 42-77. Sind Carbonkohlen autochthon, allochthon oder pelagochthon?

contact. The thickness and extent of some coal deposits are serious objections to growth *in situ*. Richthofen describes a bed in China, 20 to 30 feet thick and having an area of 600 German square miles. This would require at least 400 feet of plant remains. The bottom three feet might have been a soil in which *Stigmara* rhizomas could have grown, but the sturdiest defender of autochthony would be at loss to find a soil for the remaining 397 feet. Such a deposit could have been made only by a matt of sylvo-marine vegetation.

All allochthonous and land basin theories are untenable because transportation yields no undisturbed sedimentation; there is no transportation of organic detritus without contemporaneous transportation of inorganic material—the transportation of purely plant detritus is a superstition; subsiding land basins giving 7,000 meters of Carboniferous rocks, while neighboring basins subside at different rates, would be a marvel, for in order to account for the thick mineral beds the process of coal making would have to be intermitted a hundred times; there are no basins so great as those of coal sedimentation. The four great deltas do not equal the Pennsylvania coal-field alone; Richthofen's southeast Shansi field would require a basin sixteen times as large as the Caspian sea. The great basins must have been sea basins and a sylvo-marine forest alone explains the intermittent deposit of coal, the clays being due to influence of streams.

Kuntze classifies the theories as Autochthony, the irregular deposit of the coal-producing substance directly on the place of vegetation; Allochthony, the irregular deposit of coarse coal-producing substance on a distant place; only the powdery substance is deposited after the manner of sediments.

Pelagochthony, the sedimentary deposit of coarse substance in water of the sea directly under the vegetation; a secondary product is the powdery detritus sometimes floated away from the coal magma and deposited elsewhere as anthracite.

Autochthonous types are found in tropical or subtropical brown coal from wood-covered bogs, without sphagnum; newer peats in cooler regions with sphagnum; shore swamps and some others.

Allochthonous types are drift woods; sedimentary peats; sea

peat; paper peat, which is a bituminous clay with infusoria; Blatterkohle, a marly clay with a little sedimentary peat.

Pelagochthonous types are: (1) Normal Carboniferous coal fields. The coal beds have originated from floating forests and remains of rooted trees occur in very limited localities. Naumann's paralic coal-fields belong here; they are found in America, China, etc. (2) Sea basin deposits, consisting of limited but often very thick beds, the coal frequently thinning seaward; these contain, besides sylvo-marine remains, abundant remains of trees rooted in clay. Best seen in France. Here, in part, Naumann's limnic basins. (3) Amorphous anthracite, consisting of the finest detritus and forming irregular deposits; does not include Faser-, Staub- or Koksanthracite coal.

Penhallow⁸⁵ has given the results obtained by study of cannel-like coal from the lower Mesozoic of British Columbia. All the samples are composed of rod-like bodies more or less closely compressed, which resemble dark amber and are embedded in a cementing material. The rods show tubules within, many of them branching, which are very suggestive of *Mycelium*; granulations are common and often form zones around hyaloid areas. The features revealed by the microscope are:

(1) Absence of structure, (2) tubular ramuli of diverse dimensions, (3) rounded cavities, (4) large proportion of material in angular fragments and resembling that of the rods, (5) an amorphous substance, associated with (4), occurring as distinct flakes or as cement to unite the rods.

Appearance of structure was observed in only one rod and in that case it is evidently due to shrinkage; he thinks the spore-like aggregations are of chemical rather than of organic origin. The general character of the ramuli at once suggest *Mycelium*, but the intimate features and the arrangement forbid reference to vegetable structure. They rather resemble effects of internal shrinkage, following hardening of the outer layer, such as one sees in amber and other resins. The material occupying spaces between the rods and

⁸⁵ D. P. Penhallow, "A Preliminary Examination of So-called Cannel Coal from the Kootanie of British Columbia," *Amer. Geologist*, X., 1892, pp. 331-339.

apparently cementing them "consists of an amorphous and irregular mass full of rounded holes, thereby giving it a spongy character." It contains fragments of perhaps broken rods, the material in both being the same. The source of the amorphous material is not certain.

Penhallow offers no positive hypothesis respecting the origin of these coals, though he is inclined to think that it must be "sought elsewhere than in modified vegetable structure." At the same time, he feels that the evidence is not sufficient to justify the assertion that they did not originate in vegetable structure.

In 1892 and 1893 there appeared papers by Bertrand and Renault describing Bogheads and related types. Afterwards those observers published their results independently. The later studies of Renault concern the matter in hand only indirectly and they will receive consideration in another portion of this work. It is necessary, however, to make detailed reference to Bertrand's contributions, for, though they consider similar topics, the conclusions have a notable bearing on the formation of coal beds; and in this connection, the stratigraphical relations of the several types must be given. Without that one cannot appreciate the full bearing of the studies. The joint study by Bertrand and Renault⁸⁶ was of boghead obtained from Permian beds at Autun, France. This deposit occupies an area of 7 kilometers by 150 to 450 meters. The chief constituent is a thallophyte, *Pila bibractensis*, which makes up about three fourths of the mass; the remaining fourth being the "fundamental material" with some clay. Vegetable débris is wanting, but pollen of *Cordaites* and remains of fishes are present.

These observers recognized the bodies of yellow, red and other tints, which had been mentioned by earlier students, but their study proved that "certain resin-like bodies represent the organic gelose and even entire organisms. A great proportion of the yellow and red bodies enclosed in coals are in this category and M. P. F. Reinsch has the great merit of making this known." The inferior gelatinous plants have been preserved in this way when buried in

⁸⁶ C. Eg. Bertrand et B. Renault, "*Pila bibractensis* et le boghead d'Autun," *Bull. Soc. d'Hist. Nat. d'Autun*, V., 1892, Separate, pp. 95, pl. 2.

ulmic materials. The Autun boghead, 24 to 25 cm. thick, is not an accumulation of resinous pellets due to injection of hydrocarbons into plant débris, but it consists of 1,600 to 1,800 beds of algæ, which sank to the bottom along with grains of pollen and the fundamental material as well as the detritus. The fundamental material is brown, rather flocculent and feebly colored. It is a precipitated brown substance analogous to the ulmic matters which color the Amazon and certain of its affluents. It contains particles of a darker material, thelotite, an infiltration which penetrates the thalli.

The Pilas were algæ of very low type. Their isolation in the fundamental material, their accumulation in beds, with traces of pressure on the under surfaces, suggest that they were floating algæ like the *fleurs d'eau*. The pollen grains, usually reduced to their coats, were a powder resting on the water with the *fleurs d'eau*. The accumulation, which may have been very rapid, was only an incident in the formation of bituminous shale. It was made in quiet waters, with little or no current, and so rapidly that putrefaction could not begin in the mass. The deposit was laid down probably in shallow brown waters, like those of the Amazon region, whose acidity is unfavorable to development of many bacteria. Nearby, were forests of *Cordaites*, which furnished the pollen.

The second paper by the same authors⁸⁷ gives results of study of the so-called kerosene shale of New South Wales, which had been utilized as a source of gas and illuminating oil. This shale, known as Hartley mineral, Wollogongite and, in some reports as Torbanite, is of uncertain occurrence. Mackenzie⁸⁸ says that the deposits are very irregular, there being no guide to discovery except the presence of fragments at or below the outcrop. Toward the border of a mass, the rich mineral becomes deteriorated and gradually passes into indurated clay, bituminous or non-bituminous shale, coal or ironstone. It occurs at two horizons in the Permo-Carboniferous of New South Wales, the most notable deposits being in the Upper Coal Measures, including the well-known areas of Hart-

⁸⁷ C. Eg. Bertrand et B. Renault, "Reinschia australis et premières remarques sur le kerosene shale de la Nouvelle-Galles du Sud," *Bull. Soc. Hist. Nat. d'Autun*, VI, 1893. Separate, pp. 105, pl. 7.

⁸⁸ J. Mackenzie, Ann. Rep. Dept. of Mines for 1896, p. 100.

ley, Joadja creek and Wollongong at the south and Murrurundi (Doughboy hollow) at the north. The only important deposit in the Lower Coal Measures is at Greta near Newcastle in northeast port of the province.

Long ago, Clarke⁸⁹ recognized the close resemblance of this mineral to the boghead or Torbanite of Scotland. He thought it due to local decomposition of some resinous wood and believed that the lens-form of the deposits and their passage laterally into shale could be explained easily by supposing the mineral to be due to drifted resinous trees, undergoing changes in shallow pools surrounded by material changing into ordinary coal. The quartzose constituents are merely sand carried by wind into the pool. The thickness of the deposit depended only on the supply of drift timber.

Wilkinson⁹⁰ says that the kerosene shale occurs in irregular lenses, sometimes in actual contact with layers of coal as at Joadja creek, sometimes wholly unassociated with layers of coal, as at Hartley, or even as forming part of a great coal bed, as at Greta. At the last locality, the boghead is a great lens in the coal, but there are many petty lenses of the same material scattered through the coal benches. At Joadja, one finds small irregular patches of bright jet-like material, plant remains lying horizontally and numerous vertical stems of *Vertebraria*, whose lustrous bright jet substance is in contrast with the dull luster of the shale.

David⁹¹ found the shale in one place at the bottom of a great coal bed; Mackenzie⁹² found it at the top in another; while in still another David found a mass of alternating coal, clay and "shale," five beds of the boghead and four of bituminous coal. At the last locality the whole mass thinned out in one direction, the several layers disappearing in succession until the last layer of boghead passed into bituminous shale. There he saw many stems of *Vertebraria*, both vertical and prostrate; in one tunnel, some of them four

⁸⁹ W. B. Clarke, "Mines and Mineral Statistics of New South Wales," Sydney, 1875, pp. 179-180.

⁹⁰ C. S. Wilkinson, "Mines and Min. Stat., 1875," p. 131; Ann. Rep. Dept. Mines, 1884, pp. 149, 156; 1890, p. 208.

⁹¹ T. W. E. David, Ann. Rep. Dept. Mines, 1888, p. 170; 1890, pp. 221-224; 1892, pp. 159-163.

⁹² J. Mackenzie, Rep. 1895, p. 104.

inches in diameter were converted into coal. Mineral charcoal is abundant in a mine in Camden County, while at Murrurundi the boghead "contains numerous fragments of mother-of-coal and small fragments of what appears to be coniferous wood like *Araucaria*, together with coniferous fruit."

In the pages already cited, David gives ten analyses by Mungaye, which show that at Murrurundi the ash varies from 17 to 68 per cent. and the fuel ratio from 0.11 to 0.24; while at Ketoomba eight analyses show ash from 10.7 to 78.1 and the fuel ratio from 0.13 to 1.10. A specimen from Joadja Creek had 77 per cent. of silica in the ash.

The material studied by Bertrand and Renault consisted of two great blocks, one in Paris and the other in Brussels, each more than one meter thick, apparently the full thickness of the deposit. Like the Autun mineral, the kerosene shale consists of a fundamental brown, flocculent material, holding algæ and remains of dead plant tissues. The algæ are assigned to the genus *Reinschia*, now extinct, but belonging to a group which was spread widely during Permo-Carboniferous times. The algæ are all separate, though, at times, owing to paucity of the fundamental matter, they are in contact, they are still independent. They were free, floating on the surface of absolutely tranquil brown water, and they rained down upon the bottom, while at the same time, under the influence of calcareous waters, an ulmic jelly was precipitated to form the fundamental material. The great specimen in the Paris Museum shows 36,000 beds of these algæ, but the proportion of algæ varies in the several layers from 0.019 to 0.900 of the whole mass. At Joadja creek the mineral is often beautiful, with a satin-like homogeneous surface, and it consists almost wholly of the algæ.

Infiltrations are here as at Autun. The most important is red-brown, in strings or sheets, and shows fluidal structure; it is harder than the fundamental material; it often impregnates leaves and wood; some plants have the property of absorbing this to a notable extent. Its mode of occurrence and its tendency to penetrate the substance of plant remains suggest great resemblance to the thelotite of Autun. The authors make no attempt to decide respecting the

source of this infiltration; they are convinced that it penetrated the deposit, if not contemporaneously, at least very soon after its formation and they suggest that it may be a kind of asphaltum, like that of lake Brea in Trinidad. The kerosene shale contains no animals except at Murrurundi, where some coprolites have been discovered. It is a charbon produced by unaltered gelosic organisms.

Bertrand's⁹³ later studies were published in a series of papers, his conclusions being summed up in a memoir presented to the Geological Congress at Paris in 1900.

The bogheads, typified by deposits at Autun of France, the Torbanite of Scotland and the kerosene shale of New South Wales are charbons gelosiques of Bertrand, accumulations of fresh water algae in a humic jelly, their fossilization being in the presence of bitumen. The basal material of all is a clear brown fundamental jelly, the dull part of the bogheads and the same as the basal material of v. Gümbel's Mattkohle. Spores and pollen have undergone maceration, but they did not liquefy. They gave two kinds of yellow bodies and they condensed bitumen strongly. When they abound, the coal, though dull, is brighter than mattkohle. Débris of vegetable matter, also a contribution by the wind, is distributed irregularly. The hardened tissues are usually brilliant, prismatic like v. Gümbel's Glanzkohle. Wood and barks can be found as brilliant coal, but this depends less on their organic nature than on the extent of alteration and their capacity to imbibe bitumen. Vegetation along river banks yielded tree-trunks, which, after imbibing bitumen, were converted into bright coal.

The algæ were *fleurs d'eau*. They consisted of gelose and a little protoplasm, which, when humefied, would condense bitumen. They descended in sheets with other accidental bodies; in times of low water, the descent would be very slow, being impeded by the

⁹³ C. Eg. Bertrand, 1, "Nouvelles remarques sur le kerosene shale de Nouv. Galles du Sud," *Bull. Soc. d'Hist. Nat. d'Autun*, IX., 1896; 2, 3, "Conférences sur les charbons de terre," *Bull. Soc. Belge de Géol.*, etc., VII., 1894; XI., 1898; (4) Caractéristiques du kerosene shale," *Assoc. Franc. pour l'avancem. des Sci.*, 1897; (5) "Les charbons humiques et les charbons de purins," *Trav. et Mem. de l'Univ. de Lille*, VI., 1898; (6) *C. R. du Congrès Int. de Géol.*, Paris, 1900, pp. 458-497.

fundamental jelly. Each ball of gelose yielded a little mass of glassy, transparent gold-yellow hydrocarbon.

The bituminous matter found in all is wholly different from the fundamental material. There is proof of its intervention, for it follows clefts made by contraction of the fundamental material, which it does not color. The coalified stems of *Vertebraria* on Joadja creek are humefied vegetable material charged with bitumen. There is no evidence that this bituminous enrichment was due to condensation of resinous matter held in suspension by the fundamental material; nor is there any evidence that the fundamental material originated from alteration of the enclosed bodies.

The accumulation could be made with remarkable rapidity. A few good days with low water would suffice. All the accidental bodies, enveloped in a humic coagulum, make a raft on the absolutely tranquil water. A very slight cause, colder weather, more water, would hinder formation of gelose and cause descent. The precipitation of brown matter was continuous but formation of gelosic matter was fortuitous; with check of algal growth, the deposit passes over to a humic coal or organic shale. The vegeto-humic deposit was fixed at once and remained unaltered. The fossilization was in the presence of bitumen, which became altered so as to be insoluble in the ordinary solvents of asphaltum.⁹⁴

Bertrand's charbons humiques differ from the charbons gelosiques in that the fundamental matter is not diluted with foreign bodies. They are typified by the Broxburn shales of Scotland, containing, according to Cadell, about 75 per cent. of ash. Accidental bodies, such as algæ, spores, pollen, vegetable débris are in small proportion. Bitumen penetrated through the fundamental jelly and enriched the shale. Bertrand finds no evidence that this bitumen is a leakage or exudation from a fermenting vegetable mass; he believes that it was in the water and that it penetrated the accidental bodies only with difficulty.

⁹⁴ After the memoir was read in the Paris congress, de Lapparent asked what is to be understood by the term "bitumen." Bertrand replied that "the term bitumen implied for him the idea of a substance charged with carbon and hydrogen, intervening wholly formed in the rock."

Gresley⁹⁵ called attention to the persistence of slate partings in the Pittsburgh coal bed as having an important bearing on the origin of coal beds. Two of them, one fourth to one half inch thick and separated by 3 to 4 inches of coal, are present in an area of 15,000 square miles. Under the lower one is a coal bench somewhat more than 2 feet thick, while above the upper one is a bench varying from 3 to 5 feet. The clay of the thin binders or slate partings is extremely fine grained, mottled, non-plastic, contains macrospores and indefinite plant remains, but no *Stigmaria*.

Accepting in full the doctrine of transport, he assumes that, at the close of deposition of the lowest bench, that mass of vegetable matter lay practically level on the bottom of a vast lake or inland sea. Such being the condition he finds difficulty in explaining the overlying shale as due to fine material brought in by currents; the shale is uniform in thickness and composition over a great area, so that the supply of material must have been uniform throughout; there could have been no changes in currents or offshore conditions during the period of deposition. The quantity is not less than 100 tons per acre. He finds equal difficulty in the suggestions that the shale consists of wind-blown dust, that it is a precipitate from solution, that it is concretionary. The supposition that these shales are substitution or replacement formations or that there was a segregation of inorganic substances during solidification or the process of coal-forming involves serious difficulties. "To suppose that such shale bands were originally thin films of chalky mud, since chemically converted into silica, alumina, iron, etc., would, I think, be exceedingly unsafe." At the same time, he suggests that the globigerina ooze, widespread "over the bottom of the Atlantic, where deepest and farthest from land would seem to furnish us with about the only way (as to physical conditions) in which our shale binders in the 'Pittsburg' coal bed can be imagined to have accumulated."

If the lower slate binder was really deposited as silt by aqueous transportation, the interesting query presents itself, How could the succeeding 4 inches of coal be formed *in situ*?

⁹⁵ W. S. Gresley, "The Slate Binders of the Pittsburgh Coal Bed," *Amer. Geologist*, XIV., 1894, pp. 356-395.

The Pittsburgh coal bed thickens toward the southeast and the slate partings, as well, thicken in that direction. The evidence favors the assumption that the organic as well as the inorganic materials came from the land surface in that direction. The absence of *Stigmaria* casts reasonable doubt upon the hypothesis of formation *in situ*, and this doubt is increased by the discovery of an aquatic fauna in the underclay of the bed, which Gresley has found to be a calcareous shale.

The extraordinary uniformity of the Pittsburgh coal bed in purity and structure, the evenness and geographical extent of its several divisions make it the most remarkable known. In explanation of its phenomena, about all that can be said safely is "that, everything being horizontally stratified, every part of it was most likely accumulated under water. I have therefore come to the conclusion that this coal is the accumulated remains on the bottom of a lake or sea of vegetable growth of *aquatic forms* (though much of it did not necessarily grow *in* the water) living afloat and dying and decaying, falling through the water." All the familiar phenomena can only be explained by an aqueous origin for the coal.

The problem of coal accumulation attracted Potonié's attention in 1886 but he published no results of direct study until 1895.⁹⁶ In that year he had opportunity to study a core obtained in the Upper Silesian coal field. This core, 750 meters long, one to 2 decimeters in diameter, begins in Saarbruck beds and ends in the Upper Ostrau deposits. As submitted to Potonié, it was complete and it was studied by him in company with C. Gaebler of Breslau. The core shows not less than 27 coal beds, each of which is in direct contact with a *Stigmaria* underclay; in most of them, remains of *Sigillaria* are present and some contain *Lepidodendron*—particularly in the accompanying carboniferous shale.

Ochsenius, who urged the allochthonous origin of coal beds, explained cases, such as are present in the core, as due to local subsidences and thought them of rare occurrence. But Potonié, as an outgrowth of broad observation, asserts that these cases are

⁹⁶ H. Potonie, "Ueber Autochthonie von Carbonkohlen-Flötzen und des Senftenberger Braunkohlen-Flötzes, *Jahrb. d. k. preuss. geolog. Landesanstalt für 1895*, pp. 31, pl. 2.

merely illustrations of the ordinary conditions. "The allochthonous formation of fossil humus beds is not the normal, as Ochsenius maintains, but autochthony is the normal, exactly as in the corresponding beds of the present day." But this does not exclude contributions from other localities. He cites the abandoned ox-bows of the Mississippi, into which drift wood is thrown at high water, but which are filled eventually with autochthonous peat in which the driftwood is enclosed. The existence of *Stigmaria* in intervening beds is a normal thing and to be expected, as appears from conditions in cypress swamps of North America. Its existence in the coal itself is explained by autochthony, for, on that hypothesis, the old decaying vegetation becomes soil for the new. Indeed, the only difference between deposits of the several geological periods is in character of the vegetation, there is none in the mode of accumulation.

He finds a fossil swamp of the American type in the Miocene deposits of brown coal at Gr. Raschen near Senftenberg, which contains, among other plants, *Taxodium distichum*. The brown coal is 10 meters thick and shows several generations of forests, one above the other, the stumps remaining rooted in the brown coal. Every feature of recent swamps is reproduced there except that the humus has become brown coal. Many of the stems are hollow, containing more or less of Schweelkohle. It is worthy of note that an old peat bog exists on the clay overlying the brown coal, and that, in the humose sand covering the peat, there are trunks of *Pinus silvestris*: the conditions favoring accumulation of humus continued there until diluvial time. The Schweelkohle is due to resinous exudations from broken parts of the tree—the familiar process of closing wounds.

Absence of stumps in no wise proves allochthonous formation. If the fossil moor had borne only non-resinous dicotyledons, the Gr. Raschen condition could not have come about. The fact that *Stigmariæ* are often filled with sand is no evidence of allochthony, for hollow alder stumps in West Prussia swamps, exposed to high water, are filled with sand even to the roots, so that they must be cleaned out before the axe is applied.

In a later paper,⁹⁷ Potonié says that having supported the cause of autochthony, he must describe a deposit of allochthonous type. The distinctions are simple; in plants of autochthonous origin, the more tender parts are preserved but they are practically wanting in those of allochthonous origin. In connection with coal beds one has to do chiefly with autochthonous plants; but in Culm localities he has to do with "Haecksel," shreds of plants, which are characteristic of allochthony. These fragments are at time large enough to show by their arrangement the direction of the transporting current.

Allochthonous deposits of carbonaceous material have few botanically recognizable plants; many stems and branches, often coal coated but with surface sculpture so obscured that determination is impossible; stems of the *Knorria* type are of frequent occurrence; while *Stigmara* is almost wholly absent, those which do occur being imperfect. Sub-surface organs can be carried away only after having been washed out from their place: other portions of plants must be the essential material of a transported mass.

He presents the following contrasts.

Autochthony.

1. Coal beds common.
2. Haecksel deposits absent or insignificant.
3. Determinable plants numerous, especially in roof.
4. Few indeterminable casts.
5. *Knorria* rare.
6. Abundant *Stigmara* in the liegend. With their appendices.
7. Excellent preservation of ferns.

Allochthony.

1. Coal beds are.
2. Plant remains prevailingly Haecksel.
3. Few determinable plants; if coal bed, Haecksel in the roof.
4. Indeterminate casts abundant.
5. *Knorria* abundant.
6. *Stigmara* absent or rare; they are without appendices.

Potonié presented a brief systematic discussion of the whole

⁹⁷ H. Potonié, "Die Merkmale allochthoner palaeozoischer Pflanzen-Ablagerungen," *Naturwiss. Wochenschrift*, XIV., 1899, pp. 81, 82.

subject in 1905;⁹⁸ since that time, in successive editions, he has widened the scope of his inquiries until, in the fifth, the presentation covers every phase with abundant illustration from German areas and references to those of other lands. Only certain portions of the work can be referred to in this place but, farther on, many citations will be made. He approaches the subject from the double standpoint of stratigraphy and palaeobotany.

The coals and allied substances are termed Kaustobiolithe, because they are combustible rocks of organic origin. He groups them into—

Sapropel deposits, originally “stinking muds” composed of aquatic animals and plants,

Humus deposits, derived from land plants.

The former include the cannels, the oil shales and, as a derived product, petroleum; the latter include the ordinary brown and stone coals. The difference in origin of the two groups is evident from the physical composition shown by the microscope as well as by the chemical composition, the Sapropels yielding compounds of the paraffine group while humus deposits yield compounds of the benzol group. The Sapropels are formed in quiet, almost or wholly stagnant water and are of limited extent; whereas the humus deposits were formed as are the moors of to-day and are of vast extent. He illustrates the modes of origin by description of a great bog in northern Germany, which exhibits the passage from sapropel muds at its shore, to the Flachmoor, well wooded; thence by the Zwischenmoor, with changing type of trees, to the Hochmoor, hour-glass in form, which is treeless except alongside of rivulets. He compares the conditions with those existing in sapropel and humus deposits of the older periods. The existence of both autochthonous and allochthonous deposits is recognized, but he asserts that the former have been the prevailing type throughout and that, in every age, the latter have played an insignificant part.

Potonié finds a strong argument for autochthony in the surprising resemblances, chemical and physical, existing between beds of

⁹⁸ H. Potonié, “Die Entstehung der Steinkohle,” *Naturwiss. Wochenschrift*, IV., 1905, pp. 1–12; the latest edition is “Die Entstehung der Steinkohle und der Kaustobiolithe überhaupt,” fünfte Aufl., Berlin, 1910, pp. 225.

brown and black coal on one side and the modern Flachmoor on the other. The laminated structure is frequently present in peat. The vast extent of some beds of comparatively pure coal cannot be paralleled in recent autochthonous deposits, but the latter are of great extent in some regions, whereas no extensive areas of allochthonous carbon deposits are known to exist anywhere. He lays great stress upon the occurrence of sub-surface parts of fossil plants in the soils where they grew, the so-called petrified humus-soils. He emphasizes especially the mode in which the *Stigmaria* rhizomas and their appendices penetrate the underclay of coal beds, spreading out and interlacing in such a manner that transport is inconceivable. They must be in place. Equally conclusive are the modes in which roots of *Calamariaceæ* rhizomas occur in the clays. This almost universal underclay was the soil in which were rooted trees introducing the moor-formation.

The occurrence of forest beds in stone- and brown-coal formation is not infrequent. He notes that at White Inch near Glasgow, Scotland, and that near Senftenberg. Sometimes the profile is shown in the roof; sometimes there are successive forests embedded as at Senftenberg, where erect stumps are associated with prostrate trunks. These are conditions familiar to students of modern swamps. The mode in which the *Stigmariæ* have developed indicates, in some localities, even the prevailing direction of the wind at the time the trees grew. The growth of reeds in banks and the parallel arrangement of their roots are the same in Mesozoic, Cenozoic and recent deposits.

Potonié carefully distinguishes the features of autochthonous deposits as contrasted with those of allochthonous origin, elaborating the discussion given in the paper just cited. He states that *Stigmaria* is not rare in the Commeny basin and that his search there for that plant was rewarded abundantly. He discovered a fine autochthonous stump, with spreading stigmarian rhizomas, still retaining the delicate appendices, the whole occupying a space of 6 meters diameter. He found there also a fern tree, almost completely preserved and with a frond attached to the stem. He concludes that the condition must have been that of great quiet to permit so nearly complete preservation.

Potonié's description of secondary-allochthonous formations, due to erosion and transport of materials from beds already existing, will find place in another connection, as will also his arguments drawn from the testimony of the fossil plants, respecting which his authority is unquestioned.

Ochsenius⁹⁹ published many noteworthy papers but that of 1896 is especially important in this connection. The author recognizes the force of the objection to allochthony—that, as running water carries organic and inorganic materials together, the deposit should be an indiscriminate mass of both kinds but his recent study of coal beds in the Lahn country has convinced him that phenomena observed in the Frische Haff present a true explanation and destroy the force of the objection. The history of the Frische Haff is complete since 1510.¹⁰⁰

The Vistula, a stream laden with everything that can be drawn from a rich lowland province, gives off an arm at Peickel, the Nogat, which flows northeast to the long narrow Frische Haff, separated from the Gulf of Dantzic by the Frisch Nehrung or lowland, and communicating with the gulf by the Pillauer Tiefs at its northern end. For convenience of discussion, he confines his attention to the Nogat, ignoring the old Vistula and the rivers which enter from the east.

Under the supposed conditions, the sea having control and the Haff being filled with salt water, a marine bed is deposited on the floor. Such beds occur locally at the bottom and higher up in the series of coal deposits. Phase 1 of coal formation is brought about through sanding up of Pillauer Tiefs by wave action, and the consequent conversion of the Haff into a fresh-water basin by influx from the Nogat. The débris brought down by that river, an indiscriminate mass of organic and inorganic material, will be deposited on the bottom. If now the sea cut a shallow passage through the lowland, floating stems and twigs would form a "rake" at the head of the

⁹⁹ C. Ochsenius, "Die Bildung der Kohlenflötze," Verhandlungen, II., Erste Hälfte, pp. 224-230.

¹⁰⁰ The Frische Haff is a great sound on the border of the Gulf of Dantzic, about 60 miles long by 5 to 7 miles wide. It may be compared as to superficial area and position to Lake Ponchartrain on the Mississippi delta.

passage. If the water-surface of inflowing stream be lowered, a "barricade" of wood would accumulate in curves and narrows of the Nogat, to become compacted in time—a familiar phenomenon in this day. This "barricade" would prevent passage of large wood and only fine material, "Spulgut" would go over to be deposited as a layer in the coal basin, *i. e.*, the Haff. Brushwood would be caught by the "rake" beyond. Thus a bituminous shale with plant impressions and paper-like laminæ of bright coal would accumulate.

Phase 2 comes with moderate height of the water. Now there goes with the "Spulgut" also the "Sperrgut," stems, rooted stumps, branches and the rest, which the Vistula pushes over into the Nogat; but the "rake" does not permit its escape to the sea, it circles round in the basin, finally sinks and forms pure coal. So much of the mud as does not pass through the "rake" will accumulate on the borders or be mingled with the coal magma, as clay is in the globigerina ooze; or it may form bands in coal beds. Repeated sinkings of waterlevel in the feeding stream, the Nogat in this case, would give a clay shale like the floor as roof, the roof of the coal. No sand or gravel could pass the "barricade" but it would be heaped up there. Phase 3 comes with a high flood, which overthrows the "barricade" and pushes all into the coal basin. The sand and gravel form sandstones and conglomerates as roof of coal beds and formation of coal ceases. The woody portions become at most only isolated stems buried in the "Rollgut"; by repeated pressure they may perhaps be pushed into an oblique position. If the "rake" be torn away, the seawater again enters the basin and lays down a marine bed.

This is the characteristic succession in coal bed formation. All depends on the condition of the water-level. Changes in that cause alternation of clay, shale, coal and psammite, and effect the sharp mechanical separation of those substances by the easily explained formation of "Rakes" and "Barricades." The elevation of important mountain ranges in Carboniferous and Tertiary times afforded abundant material for widespread lowlands, approximating sea-level. These advanced seaward and their luxuriant forest growth yielded material for the stone-and brown coals. Networks of rivers must have cut through the lowlands and must have deposited their loads

in huge depressions. It is clear that many channels fed the coal basin, but all worked after the same fashion. The process throughout was that which Ochsenius terms "Barrenwirkungen" or barricade action.

The memoir discusses many details, rock fragments in coal, stumps filled with sandstone, the occurrence of gypsum, the presence of land shells, all of which are explained very readily by the theory. The conditions at Senftenberg, described by Potonié, are clearly due to this barricade-action.

The numerous coal beds of the Carboniferous were deposited quietly, but they are rarely more than 15 meters thick; whereas the brown coal beds are comparatively few in number, show irregular deposit and at times attain a thickness of 50 meters. The explanation is simple. The soft plants of the Carboniferous had, at most, a diameter of one meter and a height of 40 meters, so that they floated easily in a few meters of water over the "barricade"; whereas the Tertiary and Quaternary giant trees had a diameter of 10 meters and a height of 170 meters, so that they needed a depth of, say, 15 meters to float them over the "barricade." Clearly a depth of one meter would sink more quickly to some centimeters so as to permit only "Spulgut" to pass than would a depth of 15 meters—whence the more frequent interruption of coal deposit in the Carboniferous and the great constancy of formation in Neozoic time.

Almost all our mighty coal deposits are freshwater formations, which came into existence through the factor of "Barrenwirkungen." Autochthony holds in their formation an exceedingly limited place in comparison with that of allochthony.

Schmitz¹⁰¹ has contributed a series of important papers to the literature of the subject.

In 1894, he regarded the *in situ* doctrine as merely a hypothesis. The presence of transported pebbles in the coal itself rather favors the doctrine that the coal is composed of transported materials.

¹⁰¹ G. Schmitz, "A propos des cailloux roulés du houiller," *Ann. Soc. Geol. de Belgique*, XXI., 1894, pp. lxxi-lxxv; "La signification géogénique des Stigmaries au mur des couches d'houille," *Ann. Soc. Sient. de Bruxelles*, XXI., 1897, 6 pp.; "Formation sur place de la houille," *Rev. des. Quest. Scientifiques*, Avril, 1906, 35 pp., 9 pl.

These pebbles, he had discovered, are much more numerous than had been supposed. They are covered with a carbonaceous patine and are found mostly in the lower portion of the beds; he never saw any in the upper portions. The patine suggests that the pebbles may have made a long journey in fermenting pulp, and he thinks that their presence with this coating is confirmatory of Renault's opinions respecting the conditions of deposition of materials composing the coal. At the same time, the "French theory" of the origin of coal, though probable for the ensemble of the coal formation, does not explain the underclay. As for Belgium, the special, the constant facies of the mur is evidence of formation in place. The convincing fact is the presence of *Stigmara* in the mur with interlacing of the rootlets. *Stigmara* remains in the roof are fragmentary.

In 1897, Schmitz reviewed Potonié's paper on Autochthonie; he recognizes that the mur is autochthonous but is not satisfied that that necessarily involves the conclusion that the coal itself is autochthonous also. A mur without coal is evidence of erosion, that its vegetable cover has been washed away. If there be coal without mur, it is allochthonous. A thick bed may be autochthonous below and allochthonous above. While recognizing the valency of many of the arguments presented by Potonié, he is not convinced that they are final.

In 1906, he reviewed the whole subject. His own position in 1896 was that of uncertainty between the old doctrine of autochthony and the new forms of allochthony presented by Fayol and Grand' Eury. Many phenomena observed in the Belgian basins seemed to support Fayol's hypothesis, but the mur, with *Stigmara*, clearly *in loco natali*, is a fact which cannot be ignored. Autochthony found its chief support in conditions observed in recent swamps, but the knowledge of those was too imperfect to make the argument wholly satisfactory; so that Schmitz, at that time, was inclined to hold an intermediate position and to think that both doctrines might be true.

But Potonié's later publication,¹⁰² based on the study of swamps in a great area, goes far toward removing objections. Schmitz summarizes the processes described as occurring in the formation of

¹⁰² "Die Entstehung der Steinkohle."

Sapropel; the gradations from peat to coal; and asserts that all point toward autochthony. He antagonizes conclusions drawn from the presence of vegetable matter in material obtained by deep-sea dredging in the Gulf of Mexico, for that is mingled with ooze and proves nothing for transport. He maintains that vegetable pulp cannot be transported far without notable loss and he urges that black waters from swamps soon lose their color through oxidation, as appears from conditions in the Congo, Rio Negro and other rivers. De Lapparent has protested against the "fascination of present causes" and Schmitz admits willingly that it is an error to seek in the present an absolute representative of the past; but he asserts that it is equally an error to disregard the present in the study of the past.

Schmitz presents an elaborate argument. He traces the formation of Sapropel in an arm of the sea, the encroachment of vegetation, the formation of a bog covered by trees—the *tourbière boisée*, the loss of moisture and the destruction of the forest, the formation of the moss bog with *Sphagnum*, *Scheuchzeria*, etc.—the *tourbière bombée* or hochmoor, which may continue to rise until it reach the heath stage—that of final decrepitude. He shows how this normal development is often interrupted, that a newer stage may return to an older stage or may originate without existence of previous stages.

The wooded bogs are modern representatives of the Carboniferous type. They show conditions observed in the coal beds; peaty maceration disintegrates the most resistant plants so that one rarely recognizes the parts. The mode of growth in bog plants resembles that of the coal plants; the root is radial not tap. He describes an extensive bog in Hanover, in which the peat had been burned, leaving exposed great tree-trunks, the luxurious crown existing when the bog was wooded; if that bog had been covered with sediment during the life of those trees, there would have been a legion of autochthonous tree-trunks.

The immensity of the great coal areas, to be compared with the immensity of modern bogs, must not be disregarded. One cannot think of the great Westphalian-Belgian-English basin as a mere lagoon to be filled by rivers; and Schmitz asks how vast must have

been the low country to yield humic material for the coal beds of that basin. He thinks that to accept the land conditions necessary would require too great draft on one's credulity. But the case is wholly different with the peat bog theory.

Schmitz concludes that the coal systems consist of allochthonous rocks and autochthonous coal beds. The underclay is not a special sediment; it is a sediment modified by the establishment of vegetation. There must have been some allochthonous deposits of carbonaceous matter, but they were merely local. The accumulation as a whole was autochthonous, after the manner of the forested swamps.

Sterzel¹⁰³ thinks that very probably no theory of formation is of universal application, the conditions being unlike in different regions, even in different parts of the same region. In studying the Zwickau region area, he became convinced that plants embedded in shales accompanying the coal are not in their original place, for they are broken, they are in different stages of decomposition, their remains are mostly parallel to the stratification, and they show distinct evidence of sorting due to currents of water. Plants *in situ* occur only locally.

Some features favor belief in the autochthony of coal; the narrow variations in thickness of important beds within great areas; the small proportion of ash in many beds; the localization of *Stigmaria* in the Liegenden; the occurrence of erect stems in the Hangenden. But there are others equally favoring allochthony; the distinct lamination of the coal; the mineral matter, often forming a considerable part of the bed, is mostly clay, the same with that of the roof and floor, and it tells of quiet deposition; *Stigmaria* occurs abundantly in the roof of coal beds; erect stems are of exceptional occurrence.

The greater number of phenomena favor allochthonous origin of the Zwickau coal beds. They were deposited in a lake basin surrounded by forested swamps. The gently inflowing waters carried little mineral matter and the plant material accumulated long time on the bottom, where it was converted slowly into coal. When the

¹⁰³ T. Sterzel, "Palaeontologische Character der Steinkohlenformation und des Rothliegenden von Zwickau in den Erläuterung zur geologischen Spezialkarte," Section Zwickau, 1891, pp. 87-142; "Mittheil. aus d. Naturw. Sammlung d. Stadt-Chemnitz," 1903, 22 pp.

water-courses swelled, a great quantity of material, inorganic detritus, was brought down to form the intervening bed, on which, when quiet was restored, the plant material was deposited anew. Periodical changes, slight crustal movements, variation in fall of rivers, lead to deposit of a great mass of rock over the coal bed; the thickness of this intervening rock depending on the extent and continuance of those changes. When quiet returns, the forested swamp again expands. Many localities with particular species of plants had been destroyed wholly and those forms do not reappear in later beds—an explanation of the irregular occurrence of plant-forms in the series.

The lake was comparatively deep, for the Zwickau measures are about 400 meters thick. By accepting this hypothesis of a lake, one finds explanation also of the origin of the great salt-content characterizing the Zwickau deposits—in 1854, 400,000 kilos of sodium chloride and 15,000 kilos of calcium chloride were obtained from mine waters of the Tufen Planitzer beds.

In 1903, Sterzel qualified a statement made on p. 90 of the preceding paper, which refers to the value of erect stems as evidence. The only stems of that sort, observed by him, were "Sargdeckel," the "coal-pipes" of English miners. One *Sigillaria* stump, examined by him, was completely cut off at the base, with no trace of *Stigmara*. It had been torn from its place by running water, robbed of basal branches and then deposited in the roof of the bed, where its softened bottom was flattened under pressure. He notes that the overlying rock is sharply defined, that there is no passage of plants from the coal, such as would be the case if the place of plant-growth were flooded by masses of rock material.

Lemiere¹⁰⁴ presented a memoir to the Geological Congress of 1900, which discussed the conversion of vegetable matter into coal. In 1904, he returned to the subject and considered in addition the manner in which coal beds accumulated. The discussion is based largely on the assumption and conclusions of Fayol that the coal

¹⁰⁴ L. Lemiere, "Sur la transformation des végétaux en combustible fossiles," *C. R. Congrès Géol. Intern.*, Paris, 1901, pp. 500-520; "Formation et recherches comparées des divers combustibles fossiles," *Bull. Soc. de l'Ind. Min.*, 4^me. ser., IV., V. Published separately, 1905. Citations from pp. 70-142.

beds were formed of transported vegetable matter deposited in basins of deep water. In this later memoir, he discusses the laws governing deposition of inorganic materials of varying density and shape, on lake bottoms in tranquil water, on beds of streams and on shores exposed to the action of waves. This completed, he applies the ascertained principles to explain the formation of coal deposits.

The basins in which those deposits were laid down were ordinarily gaping faults, very long except where divided transversely by uplifted granite, and, in many cases, the fault is still apparent. Streams began to flow into the basins at once. Where the fault valley was divided transversely by uplifted granite, lake basins were formed like Commentry, Montvicq, etc., in which the beds are irregular. At other times the fracture valley retained its length and was wide enough to be a strait or estuary, common to several rivers and bordering on seas extensive enough to be affected by tides and waves. Respecting the latter he makes the frank remark: "It is hardly possible to admit that the areas of coal deposit were in direct communication with the high sea, because high-level floods are little compatible with free access of this [the ocean]; now, the floods are a condition, *sine qua non*, of vegetable contributions; it is necessary, then, to admit that the areas of deposition were lagoons, sheltered from the ordinary tides, fronted by vast low plains, themselves above the tides and furnishing few coarse elements to the river load."

Other basins retaining their length, were less affected by marine conditions, possibly because of the narrowness or because of variations in level. Of such is the great syncline extending from Moulins to Decazeville. The deposits are lacustrine. The form of the depression affects the speed of currents and therefore the type of deposits; if broad, the rivers from different points form deltas, but if narrow, the speed along the middle is such as to sweep away such deposits. The contrasting conditions are shown by the Saint-Etienne and Rive-de-Gier divisions of the Loire coal basin.

The vegetable matter, to form coal beds, was brought in mostly during floods; some of it remained afloat; some was held in suspension; while some, which had undergone thorough maceration,

sank immediately. But all alike were deposited at last on the soaked talus of the delta. The lake basin, in which the deposition was made, is conceived to have been quite deep, for Lemièrè's diagram shows curves to a depth of 350 meters and the last is still at considerable distance from the bottom; it is supposed also to be large in comparison with the breadth of the tributary streams. The important source of plant material is the space along the streams between the average low water line and that reached by high floods; but the still higher portions of the drainage area, being exposed to rain and wind, would contribute.

During a long period of low water, little aside from inorganic matter would be carried to the basin; but when that was followed by a period of heavy rains, the forested area was invaded, the vegetable contributions were increased, while inorganic contributions were decreased. The forest soil was covered with humus, which had been accumulating without cessation. The soil, thus covered, became increasingly unfavorable to vegetation, whose roots as Grand' Eury says, hate to penetrate it deeply. Lemièrè thinks this a "peremptory argument against formation *sur place* of coal beds formed by aerial plants very different from those which have formed peat bogs. That the forest might continue and might renew itself after destruction, it was necessary that the soil be cleared away at intervals by winds, rains and especially by floods."

The humus, already macerated and denser than living plants, was swept off first; afterwards, the living plants would be uprooted and broken. The macerated humus, being denser, was deposited on the convex surfaces of the delta, while the living plants had to become watersoaked before sinking, so that they were superimposed upon the other plant material. They would come to rest more abundantly in the bays between deltas, so that one should find more of volatile matters in coal laid down within the bays than in that deposited on the delta slopes, along the axes of the currents. The volatile should increase as one departs from those axes but it should decrease with the depth at which the vegetable matter was deposited.

Floating islands are possible, since a flood might tear off bodily part of a forest, which, carried down, might float for a while and

then sink to give the appearance of growth *in situ*. If the storm continue long enough, it would wash off the soil itself, which would become an intercalation in the bed. If the flood return, attaining a higher stage than before, another area of forest region would be torn off to form a new bench of coal, possibly directly on the other. When the flood subsides, the superficial currents would find only inorganic materials on which to act, and the first deposit would be mud to form the roof of the coal bed, after which would follow some sandstone and conglomerate. Between floods the vegetation is restored and the area is increased by encroachment on the lake. During this long interval, the flora might be changed.

Lemière is convinced that, by his hypothesis, he has succeeded in explaining converging beds, parallel formations and floating islets. All are allochthonous; aerial plants have formed no autochthonous beds, for no erect stem has been found in the coal; in fact, the plants could not thrive in a humus not nitrefied. Peat cannot become coal, as its tannic acid checks the process of conversion. He applies his doctrine with great ingenuity to several basins in France and finds it confirmed in all.

Lemière¹⁰⁵ has published several papers in more recent years and he presented a résumé of his opinions in 1910. In that he expresses surprise that in recent congresses the dominant opinion was that coal beds are ancient wooded-bogs buried by successive subsidences, because this opinion involves the supposition that the coal beds were not formed in the same way as the sterile beds which enclose and, at times, penetrate them. This opinion is based upon palaeobotanical evidence, which is often untrustworthy, providing two-edged weapons, available equally for defenders of each theory. It is necessary to discover some criterion which will be conclusive. In an earlier paper, he had demonstrated finally in geometric form that the peat bog theory leads to arrangement of beds unknown in nature. In this he proposes to restudy the conditions after the same method, avoiding palæontological discoveries, and availing himself of discoveries which have the character of certitude. He describes three types of structure observed in areas of the coal formation.

¹⁰⁵ L. Lemiere, "Résumé des théories sur la formation de la houille," *Bull. C. R. mensuels. Soc. Ind. Min.*, Sept., 1910, separate, 19 pp.

The first type is that of the Hainaut coal basin in Belgium, a small area, 15 kilometers wide and separated from the Campine basin at the northwest by 60 kilometers of older rocks, while on the southeast it is bounded by a fault. The fossils show that, at times, this basin communicated with the sea. The deposits are thin at the north, where the beds have remained unaffected by subsequent disturbance; but they thicken to 3 kilometers toward the southerly border of the basin, where the disturbance increases as the fault is approached, the downthrow having caused close folding. The hinge of movement was near the southeast bounding fault. If the peat bogs were formed at the unvarying sea-level, the first of them should have had, when the basin was filled, an inclination of 25 cm. per meter and the last should be almost at sea-level, while the intermediary beds should converge toward the shore line at the northwest. The conditions being absent, it is evident from this mathematical demonstration that the coal beds are not buried peat bogs. The warning against the dangers of dependence on palaeontology is repeated, and the necessity for the warning is proved by the discovery of the Bernissart iguanodons in rocks other than those to which the animals belonged, as well as by the possibility that some day remains of fossil man may be discovered under a landslide from a chalk cliff.

The second illustration is that of an area, increasing in extent as it deepens. There, convergence of the beds toward the hinge of movement would not be a criterion. The upper beds should be of greater extent than the lower. This is to explain conditions existing in the Appalachian basin, where one thick coal bed, the Pittsburgh, has an area equivalent to not less than 400 kilometers square. It is difficult to understand how materials from the anticlinal borders could reach the central parts of such a synclinal to give parallel beds there. In the central parts of the basin are great masses of red shale and beds of limestone and the coal beds are not rigorously parallel. He is inclined to think that the materials within the central parts are due to precipitation (from solution) without mechanical transportation from the borders. One cannot assert

positively that in this area peat bogs are excluded from consideration.¹⁰⁶

The third illustration is from the basin of Vendee, which is an isoclinal formation in an isoclinal valley, bounded on one side by a fault. The reference to this area is brief. Lemièrre states that the phenomena of the *faisceaux* at the north and the dips in the basin suggest, *a priori*, that here one has a case of peat bog formation. But he plots the conditions in a diagram and states that, as shown thus, they are evidently due to influence of the fault.

He concludes that the French coals as well as those of the Franco-Belgian basin are not old peat bogs but are of alluvial origin and that the same conclusion is probable for the coal beds of North America. These conclusions do not proscribe the theory of peat bogs; on the contrary they appropriate those conditions and their results. All that is insisted on is that, at present, we can find no trace of successive deepening of feeble amplitude and repeated for each bed; but there are evidences of many subsidences, important or at distant intervals, corresponding to the *faisceaux* of beds.

Lemièrre, feeling himself no longer in danger of being paralyzed by the question, Is coal formed *in situ* or as alluvium?, proceeds to show wherein his doctrine differs from other forms of the transport theory. As the distinction depends in great measure on his conception of the mode in which vegetable matter was converted into coal, the details have no place here.

This extended reference to Lemièrre's publications is justified by the fact that he has presented the characteristic of the transport theory more fully than most of his predecessors and has attempted to explain all the conditions as far as they are known to him.

Stainier,¹⁰⁷ whose numerous contributions will find consideration in another connection, believes that formation of coal beds is essentially a geological problem and he maintains that geologists have been negligent in that they have left the discussion too long to the palæobotanists. Fayol and Grand' Eury, by studying the matter

¹⁰⁶ The diagram, illustrating the structure in this second case, shows a bounding fault on one side, such as limits the little basins in France.

¹⁰⁷ X. Stainier, "De la formation des gisements houillers," *Bull. Soc. Belge de Géol.*, XX., 1906, p. V., pp. 112-114.

geologically, have succeeded in solving the problem for the basins of central France. He hopes by following their methods to solve the problem in the great basins of northwestern Europe.

If one study not the coal beds alone but also the whole series of deposits in those coal basins, he finds that their strata differ in no wise from those of terranes, whose marine origin is recognized by all. No feature of coal beds suggests a different origin for them. On the contrary, when one endeavors to explain the formation of coal beds by the *in situ* doctrine, he find himself, at each step, contradicting the best established laws of geology. These contradictions, naturally not apparent to the botanists, ought long ago to have spurred geologists to make investigations for themselves. They have led Stainier to believe that coal beds, like the encasing rocks, are of purely sedimentary origin.

For him, the coal plants grew on continents, bordering great depressions, into which meteoric agencies carried the vegetable débris along with materials torn from the land by erosion. These materials, vegetable and inorganic, were mingled intimately while the water was in agitation; but in proportion as the condition of calm was re-established, they were thrown down to the bottom in a well defined order, determined by density of the materials. In cases where the succession is complete, there was formed, first, a bed of sand, ultimately becoming a bed of sandstone; then a peculiar, irregular rock, which constitutes the mur and contains the denser parts of the vegetables, *i. e.*, the sub-surface organs; then the remaining portion of the vegetable débris was deposited to form a coal bed; and finally, the impalpable elements, fine clays, reached the bottom, giving tender fine shales, the roof of the coal bed.

The reasoning on which the conclusions are based is to be given in a memoir not yet published.

Ashley¹⁰⁸ has offered suggestions which are not without interest here. Adopting the doctrine of autochthony, he ignores in his calculations the cannels as well as other merely local deposits, which are allochthonous and therefore outside of the discussion. He finds

¹⁰⁸ G. H. Ashley, "Maximum Deposition of Coal in the Appalachian Coal Field," *Econ. Geology*, I., 1906, pp. 788-793; II., pp. 34-47; "Significant Time Breaks in Coal Deposition," *Science*, N. S., XXX., 1909, p. 129.

that under exceedingly favorable conditions a peat bog has gained one foot of thickness in five years but that in one case this increase appeared to be only one foot in two hundred years. With the conditions normal, the rate of increase seems to be not far from one foot in ten years. Reasoning from the approximately ascertained ratio of volume of peat and the resulting coal, he conceives that 300 years would be required for the formation of one foot of coal, thus giving a period of about 4,000 years for accumulation of the Pittsburgh coal bed in western Maryland. The minimum period to be assigned for formation of the 300 feet of coal in the Appalachian basin is not far from 100,000 years.

In his later paper, seeking to ascertain whether or not a coal bed may be utilized as a time measure, he indicates some complexities of the problem, one of which is important. A coal bed, 18 inches thick at one locality may be 15 feet at another, the latter thickness requiring for accumulation 4,000 years more than the other. As the rocks accompanying the thinner bed show no compensating differences, the 18 inches is all that was formed while the 15 feet was accumulating elsewhere. There was either slow growth or a time-break, that is a period of no deposition, before or after deposition of the thin bed.

"Smooth-partings" are evidences of time-breaks and represent locally nonconformity between the under- and the overlying beds: a "smooth-parting" at one place may be equivalent to 40 feet of shale at another; an inch or two of cannel may have similar equivalence. Slow growth and temporary cessation of deposition are important elements of the problem.

Dannenberg¹⁰⁰ finds strong arguments in favor of autochthonous formation in the vast extent of some coal areas, the presence of the tenderest plant-parts in coal inclusions, the abundant occurrence of roots directly under the coal, and the identity of coal-forming plant species with those found in the enclosing shale rocks. Not all localities show these features with equal clearness, for in some cases there are variations along dip and strike like those in delta deposits,

¹⁰⁰ A. Dannenberg, "Geologie der Steinkohlenlager, Berlin, 1909; Erster Teil, 197 pp. The citations are from pp. 18-27.

such as appear in the basins of central France, which Fayol has proved to be allochthonous.

The deposits must have been made in shallow water; Grand'Eury has shown that the autochthonous flora of the Loire basin could not have grown in water more than 10 to 15 meters deep. There must have been a special combination of circumstances, since the deposits, in spite of the shallowness of the water, have in some basins a thickness of some thousands of meters. This can be understood if one accept a constant though variable subsidence throughout the period of deposition. A certain instability of coast line in paralic basins is proved by repeated inroads of the sea. If the sediments be laid down less rapidly than the surface sinks, marine conditions prevail. Periods of rest, possibly of some elevation, would be favorable to development of swamp vegetation, which, when subsidence began again, would be buried under muddy and sandy deposits, until a new swampy area was produced, on which vegetation began *de novo*. These movements can be followed with great clearness in the Saarbruck and Loire basins.

Similar movements in the period of man can be recognized along many coasts. Dannenberg regards the Tertiary and Quaternary history of the Netherlands as especially instructive. This he gives in detail, showing that there have been successive advances and retreats of the shore line, so that the section of Tertiary and Quaternary beds consists of sandstones, conglomerates, shales, marine beds and peat deposits, wholly similar to the succession observed in the Coal Measures. The filled river valleys observed in the Coal Measures, have their counterparts in these newer deposits. And it must not be forgotten that, in the Carboniferous time, great orogenic movements occurred, so that there was abundant material for filling the basins.

Stevenson,¹¹⁰ after studying the area, found himself unable to accept Fayol's conclusions respecting the mode in which the coal beds were formed in the basin of Commentry. He agreed fully with Fayol as to the process by which the inorganic deposits were laid

¹¹⁰ J. J. Stevenson, "The Coal Basin of Commentry in Central France," *Ann. N. Y. Acad. Sci.*, XIX., 1910, pp. 161-204, 6 pl.; "The Coal Basin of Decazeville, France," the same, XX., 1911, pp. 243-294, 2 pl.

down, seeing there the conditions of delta formation as long recognized by geologists in American coal fields; but he could discover no reason for supposing that the coal beds were formed of plant materials washed in from the drainage area. That hypothesis, as presented for this region, seems to be self-contradictory. The supposed surface conditions at the beginning of the history were such that dense vegetable cover seems in the last degree improbable; but the vegetation required by the hypothesis was so dense, that it would have been its own protection against any but a long-continued series of the most terrific cloud-bursts; in case of such a débâcle, only a small part of the vegetable matter could be deposited as a coal bed, for the trees, supposed to have composed one half of the whole vegetation, would be loaded by material around their roots, would be snags in the mass of detritus and would be buried in the sands; even the twigs and underbrush would be entangled in the mass, for there could be no sorting action in the short course of the little torrent and all would be dropped when the flood's velocity was checked on the comparatively broad delta surface, supposed to exist when formation of the Grande Couche began. Only the finest material, mineral, or vegetable, could find its way to the bottom of the basin—yet it is certain that trees make up a very considerable part of the Grande Couche. The objections presented by this writer will be considered in another connection. He thinks that the structure of the Grande Couche shows that its vegetation accumulated *in situ* and that there is no evidence to favor the suggestion that Lake Commentry was a deep water basin at the time when coal accumulation began.

Study of the Decazeville basin led him to similar conclusions respecting that area. The conditions there are very different from those in the Commentry basin, so different that any doctrine of transport formulated to account for the conditions at Commentry could not be applicable at Decazeville.

Study of investigations by v. Gümbel and Potonié led Gothan¹¹¹ to study the coal area near Fünfkirchen. The economic importance of the Liassic coals within that area had been known for more than

¹¹¹ W. Gothan, "Untersuchungen über die Entstehung der Lias-Steinkohlenflötze bei Fünfkirchen (Pecs, Ungarn)," *Sitzungsber. d. k. preuss. Akad.*, VIII., 1910, pp. 129-143.

100 years and the relations of the beds had been described by several geologists; but nothing was known which showed the mode in which the coals had accumulated. The section contains about 100 coal beds, of which fully 25 attain workable thickness in much of the area. Gothan had already discovered underclays with roots associated with Mesozoic coal beds on the Yorkshire coast of England, and it seemed probable that search for similar clays at Fünfkirchen would be successful.

He was not disappointed, though he found the difficulties in the way of study greater than anticipated.

Under the coal bed, no. 7, there is a well-marked underclay with irregular branching coaly markings, varying in diameter and in every respect resembling roots; and, at one locality, a rhizoma with its rootlets was complete, enabling him to determine the relations of the other forms. "Through such horizontal rhizomas, the analogy of this Mesozoic underclay with the Carboniferous *Stigmaria*-beds and the recent or sub-recent reed-beds is the more marked." A four-inch layer of carbonaceous shale lies between the underclay and the coal, but one cannot trace the roots in it; they cannot be distinguished in the dark material, which is so crossed by cleavage planes that none but irregular angular fragments can be obtained. The planes do not coincide with the direction of the rootlets.

Roots are seldom observed in the freshly exposed rock within the mines, but they are distinct enough where the rock is somewhat weathered. Gothan exposed the outcrop for several meters at different horizons and in the course of a day's excursion, he found well-marked underclays, with roots, associated with 8 coal beds. The analogy with Tertiary and Quaternary underclays is complete. His conclusions are that the underclay, associated in more than a dozen instances, with the Fünfkirchen coal beds, shows that these are, for the most part, of autochthonous origin, as are, predominantly, the younger and older humus deposits of the present time as well as those of the Tertiary and Palæozoic. The failure to secure proof of this origin for all the Fünfkirchen beds is due merely to the unfavorable conditions to which reference has been made. In a footnote he notes his discovery of typical underclay, with roots, just below a Wealden coal bed in a neighboring district.